Essays on agricultural policies and land use

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Abstract

Global food production will face several challenges in the future. Population continues growing, and expansion of agricultural area is becoming more difficult. A common view is that yields need to double by 2050. The goal is not without challenges: expansion will contribute to deforestation, habitat loss and carbon emissions, while productivity increases could contribute to nutrient runoffs, increased greenhouse gas emissions and land degradation. The scientific community recommends sustainable intensification as the best way to reckon with the challenges. However, adequate policy measures need to be in place for that end to be achievable. This dissertation provides new findings to support better informed policy decisions.

The essays in this dissertation examine the interrelationship between agricultural policies and land use from various angles. The approach is empiric, and the dissertation aims to further define how policy measures affect farmers' land use decisions. The empirical analysis aims to improve predictions on the effects of policy measures. Special focus is on how policies steer land use in the direction of sustainable intensification.

Essay I examines the modeling of intensive margin adjustment of agricultural land use in computable general equilibrium (CGE) models, which are widely used to analyze land use change. The analysis is based on empirical estimation of agricultural production functions with Finnish farm-level data. The results indicate that the CRESH functional form should be favored over its alternatives. The subsequent CGE model simulations showed that both the elasticity estimates and the choice of functional form affect the model results significantly. Consequently, the widely-applied CES functional forms likely underestimate the elasticity of the intensive margin adjustment, and thus the adaptation possibilities in the agricultural sector as a whole.

Essay II examines how policies and markets interact in the structural change of agricultural sector. The model applied is based on Fisher's principle, which explains variables' evolution as regards underlying fitness factors. This essay examines both land input and output markets separately with respect to both market and subsidy income. The empirical analysis employs quantile regression techniques that can shed light on the effects of the whole range of distribution values in addition to the mean effects. The results show that decoupled subsidies have increased the market orientation of the sector concurrently with increasingly inefficient allocation of land. However, the latter effect was found to dominate, which indicates a negative net effect. Additionally, the distinction between coupled and decoupled subsidies matters very little in comparison to the effects that the subsidies have when paid in one form or another. Subsidies and market incomes attenuate each other, and thus they direct structural change in different directions. Decoupling has increased land market rigidities and thus inefficient allocation of land.

Essay III examines how farmers adjust their land use to coupled, crop-specific subsidy payments. It exploits an idiosyncratic policy change in the Agenda 2000 reform as a quasi-experimental setting. The causality between the subsidy payments and production decisions could be reliably established with the standard differences-in-differences model. A range of empirical strategies suitable for the task are explored, while the results of OLS fixed effects and fractional response models are reported as they were considered the most reliable. The results vary between the models, which nevertheless does not affect the main conclusions. The results show that the reform affected farmers' land use decisions as predicted by economic theory: a crop's area increases (decreases) if its subsidy payment increases (decreases). Furthermore, allocation decisions are very elastic to coupled subsidies, especially for feed crops.

Keywords: land use, agricultural policies, sustainable intensification, CGE modeling, Fisher's principle, quantile regression, causality, differences-in-differences

Tiivistelmä

Maataloustuotanto kohtaa moninaisia haasteita tulevaisuudessa. Väestö kasvaa edelleen, ja käyttökelpoinen maa niukkenee. Yleisen näkemyksen mukaan satotasojen tulisi kaksinkertaistua vuoteen 2050 mennessä, mikä ei ole ongelmaton tavoite: viljelyalan laajentuminen johtaa metsäalan pienenemiseen, eliölajien katoamiseen ja hiilipäästöjen lisääntymiseen, kun taas tuottavuuden kasvattaminen voi lisätä ravinnevalumia, kasvihuonekaasupäästöjä sekä eroosiota. Tiedeyhteisössä nähdään, että haasteisiin pystytään parhaiten varautumaan maankäytön kestävällä tehostamisella. Tämä edellyttää asianmukaista politiikkaohjausta. Tässä tutkimuksessa on luotu uutta tietoa tarvittavien politiikkatoimien suunnitteluun.

Tutkimuksen esseet tarkastelevat maatalouspolitiikan ja maankäytön yhteyksiä eri näkökulmista. Tutkimusote on empiirinen, ja tutkimus pyrkii tarkentamaan kuvaa politiikkatoimien vaikutuksista viljelijöiden maankäyttöpäätöksiin. Empiirisen tiedon avulla voidaan muodostaa parempia ennusteita politiikkatoimien vaikutuksista. Erityisenä mielenkiinnon kohteena on kestävän tehostamisen toteutuminen.

Ensimmäinen essee tarkastelee maatalouden maankäytön tehostamismahdollisuuksien mallintamista ja parametrisointia taloudellisissa tasapainomalleissa. Suomalaisen tilatason aineiston perusteella voitiin määrittää kuinka maata pystytään korvaamaan muilla tuotantopanoksilla kuten koneilla, työvoimalla ja lannoitteilla. Tulosten perusteella nämä mahdollisuudet ovat rajalliset. Mallintamisratkaisuilla voidaan vaikuttaa tuotettujen ennusteiden luotettavuuteen. Tulosten perusteella nykyiset ennusteet saattavat antaa liian pessimistisen kuvan maataloustuotannon sopeutumismahdollisuuksista.

Toinen essee tarkastelee politiikan ja markkinoiden vaikutuksia maatalous-sektorin rakenteeseen. Tulokset osoittavat, että tukien irrottaminen tuotannosta on lisännyt markkinasuuntautuneisuutta lopputuotteiden osalta, mutta samalla heikentänyt maankäytön allokatiivista tehokkuutta. Jälkimmäinen vaikutus on dominoivampi, mikä viittaa negatiivisiin nettovaikutuksiin. Ero tuotantoon kytkettyjen ja tuotannosta irrotettujen tukien välillä havaittiin hyvin pieneksi. Tukien ja markkinatulojen keskinäisvaikutus oli negatiivinen eli ne ohjaavat sektorin kehitystä vastakkaisiin suuntiin.

Kolmas essee tarkastelee, kuinka viljelykasvikohtaiset kylvöaloihin kytketyt tukimaksut vaikuttavat viljelijöiden päätöksiin allokoida peltoalansa eri viljelykasvien kesken. Tutkimuksessa hyödynnettiin Agenda 2000 -politiikkauudistusta luonnollisena koeasetelmana. Tutkimuksen mukaan viljelijät sopeuttavat tuotantoaan talousteorian ennustamalla tavalla: sen kasvin viljelypinta-alat kasvavat (pienenevät), jonka tukea kasvatetaan (vähennetään). Kasviallokaatio osoittautui hyvin joustavaksi tukimaksujen suhteen erityisesti rehuviljoilla.

Asiasanat: maankäyttö, maatalouspolitiikat, kestävä tehostaminen

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I started my work with the intention of using CGE modeling as my main tool. Although the process turned out to be much different than I had envisaged, the experience was most useful. I want to thank both Hannu Törmä and Juha Honkatukia, the grand old men of the Finnish CGE scene, as my work with both of them provided me with many insights in economic modeling and research. I visited the Centre of Policy Studies, then at Monash University in Australia, during my PhD work. I am especially grateful to Professor Glyn Wittwer for providing me with many insights in rigorous work with economic models. Additionally, I want to mention Professor Mark Horridge and Dr. Michael Jerie, with whom I have had many enlightening exchanges on CGE models and related software.

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Contents

List of original publications

This thesis is based on the following essays, which are referred to by their Roman numerals:

I Simola, Antti (2015). Intensive margin of land use in CGE models - Reviving CRESH functional form. *Land Use Policy* 48: 467–481. https://doi.org/10.1016/j.landusepol.2015.06.026

II Simola, Antti (2018). Government payments, market profits and structural change in agriculture. *Journal of Evolutionary Economics* 28(4): 837–857. https://doi.org/10.1007/s00191-018-0583-3

III Simola, Antti, Laukkanen, M. & Einiö, E. (2018). Production decisions and agricultural subsidies - evidence from a quasi-experiment in the Agenda 2000 CAP reform. *Unpublished manuscript.*

In essays I and II Antti Simola is the sole author. In essay III Antti Simola was the lead author. He constructed data and conducted empirical estimations. He did literature review on both agricultural economic theories and methodology. He identified crop allocation as the empirical problem. He wrote the bulk of the essay. Elias Einiö and Marita Laukkanen developed the original idea of examining quasi-expriments in Finnish agricultural policies. They also provided guidance to the main author.

1 Introduction

Agriculture is one of the main users of land in global terms. Of all the habitable land, 50% is used by agriculture, of which 71% is dedicated to livestock production (Roser and Ritchie, 2018).[1] Furthermore, van Vliet et al. (2015) claim that in comparison to other land use forms, agriculture is a distinct case as it can usually be seen as the proximate cause of changes in other land use categories such as forestry. Therefore, agricultural policies should also have a central role in steering overall land use in a socially optimal direction. This dissertation aims to contibute to improved knowledge of the effects of agricultural policies on land use change.

The amount of land dedicated to food production is naturally connected to population size, and therefore agriculture's prominent role in shaping global landscapes is relatively recent. Furthermore, as the global population is still predicted to continue on its growth trajectory, some caution about land use developments is warranted. For instance, the most recent estimate by the United Nations (2017) is a global population of 7.6 billion, and a 1.1% annual growth rate. This growth is nevertheless already slowing, and it is predicted to slow further in the future, so that the population will reach 9.7 billion in 2050, and 11.2 billion in 2100.[2] In addition to population growth, increasing income and living standards, which tend to inflate demand for animal products, keeps contributing to increasing demand for land.[3] Röös et al. (2017) show that extrapolation of current consumption patterns till 2050 would require more cropland than there is available. In contrast, in all scenarios that assume a reduction in the demand for animal products, land use remains within sustainable boundaries. However, income growth is also predicted to slow in the future, which makes the extrapolation scenario less plausible. Additionally, the income elasticity of demand for food is predicted to decline with income growth, which would further dampen the agricultural land demand in developed countries (Ruttan, 2002).

The debate on the sufficiency of agricultural land for addressing humanity's needs has a long history, with varying levels of optimism and pessimism. The pessimistic view can be traced back to Thomas Malthus, who famously predicted in his essay[4] in 1798 that economic wellbeing is forever constrained by land productivity: population growth that is geometric will always have its boundaries defined by land productivity that advances only arithmetically. Ironically, that prediction already became obsolete before it became popular.[5] Historians

[1]Habitable land is estimated to be 71% of the global land area (149 million km^2), which is 29% of the total area of the Earth. Total agricultural land are is thus 53 million km^2.

[2]This prediction naturally has some uncertainty and the stated 95% prediction interval for 2050 is between 9.4 and 10.2 billion, and for 2100 between 9.6 and 13.2 billion. The earliest estimate for plateauing of population growth is around 2070, whereas at the higher end of predictions the world population would continue to grow even after 2100.

[3]The phenomenon whereby consumption of fats and proteins increases in developing countries along the income level is also known as *Bennett's law*.

[4]*An essay on the principle of population, as it affects the future improvement of society*, (Malthus, 1798).

[5]Additionally, although not commonly appreciated, Malthus himself updated his prediction to a more

have identified the century before Malthus as the era of the British Agricultural Revolution.[6] Although there is no agreement on the exact timing and underlying factors,[7] the revolution was characterized by British agricultural output growing 2.7-fold between 1700 and 1870. Chronologically it precedes the Industrial Revolution, and some claims for the causal connection between the two are also advanced (Nurkse, 1953; Clark, 1993). More recently, the Green Revolution[8] between the 1930s and the 1960s radically improved agricultural productivity in some developing countries[9] by introducing innovations in high-yielding varieties, and spreading technologies from developed countries like fertilizers and other agro-chemicals, irrigation, and mechanization, to developing countries. The Green Revolution seemed to accelerate land productivity from its previous arithmetic regime to a geometric one that could match, and eventually surpass, population growth. In developing countries, cereal output grew more than two-fold between 1961-1985 (Conway and Toenniessen, 1999). The productivity increase experienced in the Green Revolution was considered completely implausible for both Malthus and neo-Malthusian commentary as exemplified in Ehrlich (1968), D. L. Meadows, D. H. Meadows, et al. (1972), L. R. Brown and Eckholm (1974), and D. L. Meadows and Randers (2012). Nevertheless, the Green Revolution has had critics of its own, who point to its less sustainable features like land degradation and dependence on fossil energy. For instance, Smil (2000, p. 65–66) reflects the correlation between the increasing pressure on the productivity of agricultural soils and adoption of new technologies: "Mere enumeration of changes brought by intensive cropping [...] makes clear that many soils had to endure much greater impacts during the past one or two generations than they had experienced during centuries of traditional farming."

Evidently, the connection between population growth and land use is not straightforward. van Vliet et al. (2015) distinguish four distinct categories of land use change: increase and decrease in the area used for agricultural activities (extensive margin), and increase and decrease in the intensity of existing agricultural areas (intensive margin). Hertel (2011) demonstrates the most fundamental underlying factors by defining the long-run equilibrium change in land use q_L^* as an equality:

$$q_L^* = \frac{\Delta_A^D + \Delta_L^S - \Delta_L^D}{1 + \eta_A^{S,I}/\eta_A^{S,E} + \eta_A^D/\eta_A^{S,E}} - \Delta_L^S \tag{1}$$

where thesubscripts A and L refer to agricultural commodities and land, respectively. Superscripts D and S denote demand and supply, respectively. The Δ's refer to percentage

cautiously optimistic direction in the second edition of the essay in 1803 (Smil, 2000).

[6]The Second Agricultural Revolution is another term used, the First Agricultural Revolution being the adoption of agriculture in the Neolithic period.

[7]See Allen (1999) for a discussion of various theories.

[8]Also called the Third Agricultural Revolution.

[9]South America, and South and East Asia were able to gain from the Green Revolution whereas Sub-Saharan African countries have still not been able to replicate the success.

changes, and the η's to elasticities. Supply elasticities may refer either to intensive (superscript I) or extensive margin (superscript E). Δ_A^D is the change in demand for agricultural commodities driven by population growth, income levels, consumer taste changes, and agricultural policies, e.g. biofuel mandates. Δ_L^S is the change in agricultural land supply determined by other land use categories like forestry and urban developments, among others. Δ_L^D is the exogenous yield growth, which determines land demand in agriculture. $\eta_A^{S,I}$ is the intensive margin, and $\eta_A^{S,E}$ the extensive margin supply elasticities. η_A^D is the price elasticity of demand for agricultural commodities.[10]

Although it is evident that total agricultural land use, the extensive margin, is affected by demand driven by population growth, changes propagated via the intensive margin channel have been more prominent. Current agricultural technology is capable of producing more output from a unit of land than before, which has meant increasing demand for other, complementary inputs like machinery, irrigation, improved high-yielding seeds, fertilization, and perhaps in the near future big data and robotics. As a result, the demand for agricultural land has developed more slowly than it would have done in the absence of many technological innovations. Indeed, as output growth was limited almost entirely to extensive margin changes before the 20th century, productivity growth–the amount produced per unit of land–has dominated since then, and in the 21st century almost all output growth can be attributed to productivity improvements (Ruttan, 2002). This trend is likely to continue: e.g. Smil (2000, p. xviii) states that "all but a small share of increased food production during the twenty-first century will have to come from intensified cropping." Furthermore, he suggests that intensification should be based on existing inputs rather than adoption of new ones. Green et al. (2005) propose that land sparing, i.e. minimizing demand for new farmland by increasing yields, is also an ecologically preferred solution. The land sparing argument also helps to illustrate that technological change in agriculture has already helped to save a disproportionate amount of land from conversion to agriculture. Nevertheless, the majority of studies predict a small but steady increase in land use in the next few decades. For instance, the Food and Agriculture Organization of the United Nations (FAO) predicts that the increase will continue until 2050 (Alexandratos, Bruinsma, et al., 2012).[11]

There is also some promise of more radical technological disruption. For instance, artificial (or *in vitro* or cultured) meat,[12] consumption of insects,[13] and urban agriculture could radically

[10]This conceptual model abstracts from several underlying causes. For instance, another channel of adjustment is through international trade and comparative advantage, which affect the global allocative efficiency of land use and thus demand for land. Baldos and Hertel (2015) show that more open trade could prevent an increase in agricultural land use and thus help to mitigate the negative consequences of climate change for food security. Costinot et al. (2016) show that international trade adjustments have the potential to alleviate some losses in global agricultural output related to climate change.

[11]In contrast, an analysis by Ausubel et al. (2013) predicts peak farmland, i.e. that the growth of land demand in agriculture has already plateaued and will start to decline. Thus far the peak farmland prediction has not been supported by observations (Roser and Ritchie, 2018).

[12]See Hocquette (2016) for a cautious, and Stephens et al. (2018) for a more optimistic view.

[13]See van Huis (2013) for a review of the potential, and Belluco et al. (2013) for a review of safety

alter the land productivity of food production. Tuomisto and Teixeira de Mattos (2011) showed that the overall environmental impacts are significantly lower for cultured meat. Alexander et al. (2017) estimate that imitation meat and insect production, despite being still rather underdeveloped technologies, are already slightly more land-efficient than the most land-efficient animal products today eggs and poultry meat. In contrast, Clinton et al. (2018) estimate with geospatial data that urban agriculture has a rather modest global potential for increasing food security, energy-saving and ecosystem services. Expressed in tonnes of food produced, the estimate of the potential is 1.5-2.7% of current food production.[14] Ultimately, the net effect of increasing urban food production and increasing the share of land used in urban developments remains unclear.

As stated earlier, the current prediction is that the global population will increase to 9.4-10.2 billions by 2050. For the same period of time, global yields need to double for food production to be sufficient to feed that predicted population (Godfray et al., 2010).[15] There is some evidence that current trends are not sufficient for reaching that goal (Ray, Ramankutty, et al., 2012; Ray, Mueller, et al., 2013; Grassini et al., 2013). In addition, some underlying, detrimental trends that could slow down agricultural productivity are visible but not well understood: soil loss and degradation, water scarcity and salinity, co-evolution of pests and parasites, and climate change. Furthermore, productivity improvements in countries that have already achieved high productivity levels have become increasingly costly. (Ruttan, 2002).

There are also downsides to both intensive and extensive margin changes in land use. Extensive margin expansion is related to deforestation and habitat loss, both of which contribute to environmental problems. Deforestation intensifies climate change as it releases carbon into the atmosphere. Land use-related activities currently account for 20-24% of global greenhouse gas emissions originating from human activities (IPCC, 2015). Habitat loss reduces biodiversity, which could have unpredictable consequences for human welfare.[16] The Green Revolution has been widely criticized for achieving its success by many unsustainable methods. Intensification of production, especially when accompanied by inadequate use of production inputs like fertilizer and heavy machinery, is related to land degradation. Land degradation contributes to soil nutrient run-offs and loss, carbon emissions from land use change, and lower yield expectations.

It is therefore evident that the net effect of both intensive and extensive margin adjustments is difficult to evaluate overall. Additionally, the effects have a considerable amount of regional

concerns.

[14]The same estimate for monetary values is somewhat higher, 3.0-5.8%, because urban agriculture consists mostly of higher-value crops like pulses, roots and tubers, and vegetables.

[15]Godfray et al. (2010) actually refer to a less precise and earlier estimate of 9 billion people. Therefore, doubling could be considered as a lower bound estimate.

[16]Views on the significance of the loss of agricultural biodiversity vary greatly. For instance, Garnett et al. (2013) mention agriculture as “a greater threat to biodiversity than any other human activity”, whereas Smil (2000, p. 55) points out that “there is no simple link between species diversity and ecosystem stability.” Thus loss of agricultural biodiversity may or may not have negative effects on the functioning of ecosystems, a state not easily assessed in advance.

variation. Nevertheless, a large group of leading scientists have proposed four solutions that could together address the problem of achieving the required productivity gain without undue damage to the environment: 1) stop agricultural expansion, 2) close yield gaps, 3) increase agricultural resource efficiency, and 4) increase food delivery by shifting diets and reducing waste (Foley et al., 2011). These recommendations largely comply with notions of sustainable intensification (Tilman et al., 2011), which is the favored approach for tackling the dual challenge of providing enough food for future generations without causing undue environmental damage.[17]

Hayami and Ruttan (1970a,b) showed that agricultural productivity naturally develops by saving its limiting factor. For instance, change in the productivity was driven by biological and chemical (i.e. land-saving) innovations in Japan, and by mechanical (i.e. labor-saving) innovations in the US in 1880-1960. Therefore, productivity growth in agriculture is an induced innovation that affects both farm-level adoption of technologies and deliberate R&D. The model also predicts that labor-saving innovations become increasingly appealing with economic advancement, and that developing countries are less likely to import innovations from developed countries because of their lack of capital intensity (Federico, 2005). Federico (2005) shows that empirical evidence supports the hypothesis. The findings therefore implicate that land sparing is likely to take off by itself along with general economic development. In contrast, land-abundant countries that lag behind in economic development are more likely to experience development that is adversial to land sparing. Alston and Pardey (2014) show that the two distinct patterns of productivity growth can still be clearly distinguished: higher-income countries have become less labor-intensive, whereas developing countries have become more labor-intensive. Regional variation in land use challenges is therefore crucial for the recommended policy options. Developing countries face the problems of food insecurity most directly, agricultural extensification and the environmental problems associated with it. Developed countries are mostly food-secure, but their active regulation of the agricultural sector is costly and environmentally questionable, it causes harm to other countries, and it could also have adverse consequences for their own agricultural sectors' structural development.

The essays in this dissertation take a diverse view on the effects of agricultural policies on land use. The common theme is to quantify the observed land use adjustments with respect to policy measures. Indeed, Hertel (2011) suggests that quantification of adjustment responses is the primal contribution of agricultural economics to land use predictions. Each essay quantifies the effects with empirical observations. First, the distinction between the intensive

[17] Sustainable intensification and land sparing are essentially techno-optimist solutions to the challenge. A less cornucopian alternative is also proposed, namely land sharing or wildlife-friendly farming. The aim is to preserve as much biodiversity on cultivated land as possible by means of more extensive and biodiversity-rich methods such as organic and perennial cultivation systems. Fischer et al. (2008) consider the merits of both approaches and end up recommending location-specific solutions. However, Phalan, Balmford, et al. (2011) and Phalan, Onial, et al. (2011) found that land sparing seems after all to be a more promising strategy for conserving biodiversity. Stoate et al. (2009) end up recommending decreasing intensification in Europe, but the recommendation is based on purely ecological values without considering agriculture's role in food production.

and extensive margin of land use adjustment is crucial for the sustainability aspect of policies. Essay I addresses the issue of how that distinction is taken into account in current modeling work, and what options exist for improvement. Integrating plausible intensive margin responses to models should more realistically portray farmers' adaptation responses with respect to new climatic conditions. The essay shows that by applying realistic intensive margin adjustment in CGE models, the models predict greater adjustment in agricultural land use to external shocks. Second, it is important to distinguish between various policy options. For instance, the shift from coupled income payments to decoupled ones has been a major event in the evolution of industrialized countries' agricultural policy measures. Essay II evaluates the shift to decoupled payments and its effect on the structure of the agricultural sector and the consequences for the efficient use of land. The results indicate that although decoupling has improved market orientation in agriculture, it has nevertheless increased rigidities in land markets, and consequently inefficient allocation of land use. Essay III more closely examines the effects that coupled payments have on farmers' production decisions concerning the allocation of land between various crops, which thus far has been taken for granted. The results show that farmers' land allocation decisions are indeed very responsive to coupled area-based income subsidies as elasticity values over unity were found.

The essays exhibit a variety of methodological approaches applicable to the undertaking. An empirical approach based on econometric analysis is applied in all of the essays. Essay I applies a structural econometric analysis in order to estimate the agricultural production function. This approach is useful for quantifying elasticity parameters that could be applied in further analysis. Essay II applies quantile regression techniques, which are useful when considering the distributional outcomes of a policy. Essay III applies the standard differences-in-differences model, a quasi-experimental statistical technique that is useful when the causality between policy and its effects is to be assessed. Statistical analysis is not always sufficient by itself for delivering all the requisite information on a particular policy question. This is especially the case when some issues that are hard to control statistically, e.g. general equilibrium effects, are present. In the first article, the statistical analysis is accompanied by simulations performed with a computable general equilibrium (CGE) model. Such models are especially useful in predicting the overall economic effects of a policy change yet to come, i.e. an *ex ante* evaluation.

1.1 Objectives of the study

In general, this study aims to shed light on the possibilities for agricultural policies to steer land use decisions in a more socially optimal direction. Whether that direction would involve either more land sparing or more land sharing, needs to be assessed separately. Although directing land use is not an explicit goal of Finnish agricultural policy, it is evident that agricultural policies affects land use. Thus more research is needed for analysing the effects. More specifically, the objectives of the study are:

1) to quantify the possibilities for land use adjustment in the intensive margin,

2) to provide recommendations for the choice of functional form and parameterization in the CGE model with respect to intensive margin adjustment,

3) to examine whether the policy responses have significant distributional differences,

4) to examine the effects that decoupling of agricultural payments have on land allocation among farms,

5) to assess the causal link between coupled income payments and the choice of crop mix,

6) to estimate the elasticities of agricultural output with respect to subsidy payment for major crops.

Objectives 1 and 2 are considered in the essay I, objectives 3 and 4 in the essay II, and objectives 5 and 6 in essay III.

1.2 Outline

The outline of the dissertation is as follows. Section 2 discusses the background of agricultural policies and land use more broadly. Subsection 2.1 summarizes the role of land use in economic theories and practices historically. Subsection 2.2 gives a more detailed account of agricultural policies, their rationale and diversity. Subsection 2.3 more closely examines agricultural policies and the evolution of these in Finland, which is the location of all the analysis in this dissertation. Subsection 2.4 summarizes the characteristics of Finnish land use and related agricultural policies. Section 3 outlines the economic theories that form the basis of the empirical analysis, while section 4 discusses the data and methods used in this study. Section 5 summarizes each essay in the dissertation and their main results. Section 6 gives a discussion of the main findings, and section 7 concludes.

2 General background

2.1 Land use in economics

2.1.1 Land use and general economic theories

Land use was a prominent theme for pre-classical and classical economists. The physiocrats, who preceded the classical economists, considered land as the only true source of wealth. Their views were undoubtedly influenced by their land ownership status in agrarian France. Classical economists, hailing mostly from industrializing Britain made one of their greatest contributions by countering the prevailing wisdom of the central role of land in the economy. The three primary factors of production, namely capital, labor and land, were subsequently introduced to economic thinking by the classical economists.[18] One of Adam Smith's most revolutionary ideas was that the division of labor rather than the wealth derived from land is the true source of nations' wealth as productivity growth is naturally higher in manufacturing than in agriculture (Smith, 1776). David Ricardo (1817) proposed that landowners benefit from economic development via rent, which nevertheless does nothing to benefit society as a whole. On the contrary, landowners tend to favor policies that increase their rents but could be detrimental to society, for instance tariffs. The repealing of the Corn Laws, which shifted the era's policies towards more open trade, was a political achievement closely tied to classical economic theories.[19]

The prominence of land in economic thinking eventually waned when modernity, with its unforeseen technological progress turned it into an ever more trivial factor in prosperity in advanced economies. The physiocrats were a product of their times, and their case is an illustrative example of how theorizing is limited by current observations - what in agrarian societies seemed like a plausible interpretation of the functioning of an economy did not readily generalize to the industrial era. However, some of the ideas of the physiocrats lived on in the land value tax advocated already by Smith and Ricardo, and most prominently by Henry George as the single tax in his treatise *Progress and Poverty* (George, 1879). Sometimes also referred to as the perfect tax, land value tax has been seen as the natural source of public revenue as it is fixed and immovable (i.e. has inelastic supply) and thus is not subject to the most common forms of tax evasion. Land value tax also addresses the problem of deriving rent from owned land, and thus potentially alleviates economic inefficiencies and inequality. It has wide support among diverse schools of economic thought, and it is currently applied in many settings. A general recommendation for a modern tax reform by Mirrlees and Adam (2011) considers land value tax as a very promising element in conceivable tax reforms. Nevertheless, in the agricultural context land tax is little used.

2.1.2 Land use and the economics of climate change

After interest in George's land tax ideas had waned, land use became an increasingly marginal issue for economists. However, in recent years there has been a revived interest due to land's role in climate change mitigation. For instance, the Intergovernmental Panel on Climate Change (IPCC) has produced two major reports on the theme of land use, land use change and forestry (LULUCF) (IPCC, 2000, 2003). Land use contributes to climate change primarily via deforestation, which releases carbon into the atmosphere. Other land use activities with a climate impact are fertilization (a source of nitrous oxide emissions), manure management in

[18] In this context land should be interpreted more broadly as natural resources, i.e. land ownership related to rent that can be derived from natural resources extracted from a piece of land or land's productivity for renewable resources like agricultural and forestry products.

[19] As already mentioned, the connection between land use and population growth was the central theme of Thomas Malthus, who is commonly identified as one of the prominent classical economists.

livestock farming (a source of methane emissions), and forest rotations. Agricultural soil also has the potential to sequester atmospheric carbon when appropriate management practices are applied. Lal (2004) estimated that sequestration of soil organic carbon (SOC) has the potential to offset 5 to 15% of global fossil fuel emissions. However, estimates of SOC stocks and their responses to various management practices are complex and highly uncertain.[20] Obviously, evaluation of global land use change remains challenging.[21]

Estimation of the global mitigation potential of LULUCF has required substantial economic and biophysical modeling efforts.[22] For instance, Rose et al. (2012) showed with an array of integrated assessment and general equilibrium models that land use-based mitigation options cost-effectively complement other policy options such as reducing fossil fuels: 15-40% of all the required long-term abatement could be achieved with land use measures, while in the short term their role could be even higher due to the need to bridge the gap to future low-carbon technologies. In addition to active land use policies, it has become evident that the dynamic interactions of land use and atmosphere affect climatic conditions significantly and thus cannot be ignored in climate models. The modeling techniques have also contributed to an assessment of land use in a more general context.[23] van Meijl et al. (2006) assessed changes in land use in Europe with predictions from an economic (GTAP) and a biophysical (IMAGE) model of global food demand and agricultural policies. They predict that overall land use in Europe will be stable, primarily due to still increasing food demand. Further liberalization of agricultural policies was not found to cause major deviations from that trend. On the other hand, land use in Africa was found to be substantially affected. Meyfroidt et al. (2013) also underline the increasingly global nature of land use change: local land use policies could have indirect global consequences via leakage, or indirect land use change (ILUC). The authors call for more interdisciplinary and global modeling efforts to quantify such effects. In order to assess the evident uncertainties in various global development paths, Popp et al. (2017) conducted an array of land use analysis corresponding to the IPCC's Shared Socio-Economic Pathways (SSP) scenarios. The analysis concludes that low demand for agricultural commodities, increased agricultural productivity and globalized trade help to curb greenhouse gas emissions and decrease food prices.

Along with the general interest in land use, climate change mitigation has increased interest in producing biofuel, which seemed to be a good alternative to fossil fuels. Additionally, it was anticipated that biofuels could improve incomes in agriculture (Gohin, 2008). However,

[20] See Scharlemann et al. (2014) for a comprehensive review.

[21] An interesting recent development is the carbon benefits index by Searchinger et al. (2018), which aims to take into account all the main output types and quantities as well as production processes in order to evaluate them with respect to their land use change (LUC) effects. The initial results indicate that traditional methods could systematically underestimate the potential for carbon storage in non-agricultural land. Thus the research lends support to land sparing strategies.

[22] See Weyant et al. (2006) for the initial effort of taking land use into account in the integrated assessment model (IAM) EMF-21, and Noszczyk (2018) for a review of various land use modeling methods.

[23] See Heistermann et al. (2006) for a review.

numerous studies[24] have shown that the solution was more controversial due to land use effects: increased production of biofuels contributes to increased demand for land and extensive margin increases in agricultural land use. Also, the coincidence of developed countries' biofuel programs and the 2007–08 global food crisis raised some serious ethical concerns (Kay and Ackrill, 2012). Once again, economic modeling has proven to be an indispensable tool in assessing the various less obvious effects of policies.

2.2 Agricultural policies and land use

Agricultural policies have varied greatly both spatially and in time. However, several stylized facts can be identified in the literature. Almost every country intervenes actively in their agricultural and food sectors. The prime goals of agricultural policies are income redistribution and corrections of market failures (de Gorter and Swinnen, 2002). The income redistribution goal addresses equity concerns towards the farming population. The redistributional goal cannot be justified from a purely (positive) economic point of view, and it obviously has a negative effect on the allocative efficiency of public resources (Harvey, 2004).[25] Redistribution itself is affected by measures aimed at addressing market failures such as detrimental environmental effects (de Gorter and Swinnen, 2002).

Agricultural policies have a long history. Tariffs and other trade restrictions on food products are the earliest public policy interventions with direct consequences for the agricultural sector. In Britain such measures date back to the 17th century, the Corn Laws being an early example. Other early interventions include varying developmental aids for rural populations and the agricultural sector, granting land to farmers and research, and public support for extension services. Such aid dates back to the 18th and 19th centuries in the major industrial nations. Nevertheless, the era before World War I can be considered as an era of *laissez faire* or benign neglect in agriculture (Federico, 2005).

The interwar era meant great disruptions for the sector and the birth of modern agricultural policies. More modern policies, which employ direct market interventions, date to the post-World War I era, when the US developed price and income support mechanisms in order to carry their agricultural sector through a demand slump in war-ravaged Europe, which was their main export region (Hoffman and Libecap, 1991).[26] At the same time, European coun-

[24]See e.g. Keeney and Hertel (2009), Hertel, Golub, et al. (2010), Hertel, Tyner, et al. (2010), and Taheripour et al. (2010).

[25]See Bullock, Salhofer, and Kola (1999) for a normative framework of agricultural policy analysis incorporating equity concerns, and Bullock and Salhofer (2003) for a survey of redistributional analysis of agricultural policies.

[26]In addition to export market difficulties, domestic markets were affected by military expenses reverting to peacetime levels. In order to feed their own troops, the US government had incentivized dairy farmers to increase their output capacity. As demand normalized to pre-war levels after the war, prices plummeted to a level corresponding to prevailing output capacity (Federico, 2005). As a result, many farms became incapable of paying their debts (Mann, 2018). The coincidence of government-induced demand, overproduction, and farm debt has been characteristic of developed countries' agricultural

tries responded with increased protectionism (Federico, 2005). Gradually the US emergency responses developed into a comprehensive agricultural policy program, the Agricultural Adjustment Act (AAA) in 1933 (Dimitri et al., 2005). In Europe, a similar development towards more comprehensive agricultural policies coincided with the aftermath of World War II, when the non-socialist European polities decided to form an economic alliance that would bring stability and facilitate the reconstruction process. The European Economic Community (EEC), which eventually developed into the European Union (EU), agreed upon the founding of the Common Agricultural Policy (CAP) in 1960. The reform created common markets for agricultural products inside the EEC, and accompanying measures for restricting trade with other nations. Federico (2005) points out that the temporary relief programs related to the wars could have been just that temporary. In contrast, subsequent developments became a prime example of relations between interest groups and path dependencies in political economy.

Rapid technological progress in the developed countries since World War II together with more open international markets have helped to fulfill many of the original agricultural policy goals. For instance, concerns over food security have become largely irrelevant in developed countries, while the overall situation in the majority of developing countries has improved significantly. Malnutrition, where it exists, is likely to be not caused by lack of food, but inability to purchase it caused by *inter alia* poverty, inequality and power structures. At the same time, the overabundance of food and related health issues have become a problem of their own in many developed countries. Paradoxically, fulfillment of redistributional goals has simultaneously become harder to achieve: as overall living standards have increased along with technological progress, incomes in the farming sector have not been able to keep up. Engel's law states that because agricultural products are income-inelastic, demand for them grows more slowly than for non-agricultural products. Consequently, factor demand also grows more slowly in agriculture than in other sectors. Thus even in the absence of disparities in technological change between agriculture and other sectors,[27] in competitive equilibrium labor needs to move from agriculture to other sectors when income levels increase. If labor does not adjust accordingly, real incomes have to decrease in agriculture. However, precisely the opposite has happened in the majority of industrialized nations. Johnson (1987) argued that developed countries' agricultural policies have tended to maintain resources in agriculture rather than trying to facilitate migration of resources between sectors. Timmer (2009) observed that the share of labor in agriculture decreases more slowly than the sector's GDP share and is therefore

policies.

[27]This disparity was long thought to favor manufacturing (e.g. see discussion on Adam Smith's ideas in section 2.1), and thus productivity in agriculture would necessarily lag behind. However, empirical work by Martin and Mitra (2001) proved this notion incorrect as in many settings technological progress has been more rapid in agriculture. Furthermore, the study found strong evidence of total factor productivity convergence between countries in agriculture. Thus international dissemination of agricultural technologies is also rapid.

sticky.[28] Therefore, the coherence of agricultural policies is questionable.[29] Arovuori (2015) showed empirically that in the EU between 1975-2007 all agricultural policy targets developed as intended except farmers' incomes, which had declined.

Despite the radical changes in economic fundamentals, attempts to redefine objectives and policy measures have proved to be difficult. Much of the difficulty can be attributed to the disproportionate influence of the agricultural lobby. This phenomenon is in line with the theory of competition among pressure groups by Becker (1983): a minority group can gain disproportionate political influence in order to secure its own interests. The necessary reforms for dealing with problems caused by policies like overproduction and environmental degradation have been sluggish. For instance, Harvey (2004) reviews the EU agricultural policy reforms and finds the process to be characterized by multiple path dependencies that make radical reform very unlikely. Already in the 1980s agricultural subsidies began to face criticism due to its contribution to overproduction (Ackrill et al., 2008). Domestic food demand could not consume all the subsidized output, which gradually led to a need for supply restriction measures and dumping of the overproduction on international markets. This dumping in turn affected world market prices negatively and thus undermined developing countries' incentives to develop their own food production and security. Economic models have predicted large total welfare gains from the removal of agricultural policies that distort trade (see e.g. Anderson, Martin, et al. (2006)).[30]

Developing countries have experienced mixed success in their agricultural development and policies. The general expectation was that developing countries would catch up with developed countries as they are able to adopt new, more productive technologies from developed countries without their own innovation investments. However, the results have been somewhat disappointing for various reasons. First, the climatic and physical realities vary enormously in agriculture: technologies are typically location-specific and thus not easily adapted in dif-

[28]Factor mobility between agriculture and other sectors is also affected by the overall technological development of society. Alvarez-Cuadrado and Poschke (2011) showed that labor push (i.e. technological progress in agriculture and Engel's law combined) and labor pull (i.e. technological progress in other sectors) have affected structural change of agriculture differently depending on their stage of development: labor pull was more important in the early stages of industrialization, while labor push has become more important in later stages. Subsequently, Üngör (2013) showed that productivity growth in agriculture together with subsistence constraint explain 90% of agriculture's labor share variation, while the remaining share can be attributed to non-agricultural technological progress, frictions in labor markets, migration, and institutional constraints among others.

[29]Guyomard et al. (2004) showed that no uniformly dominant agricultural policy program exists for a policy with multiple goals unless the goals are explicitly ranked. Thus without such a ranking no final verdict can be made on the success of policies.

[30]In addition to trade-related allocative inefficiencies, there is some evidence of a direct link between farm-level inefficiency and subsidy payments. See e.g. Minviel and Latruffe (2017) for a survey. Although empirical work confirms the existence of such inefficiencies, they are in general found to be relatively small. One deficiency in the current literature is that it is predominantly based on static analysis. However, Minviel and Sipiläinen (2018) showed that a dynamic application does not alter the main conclusions of subsidies causing inefficiencies, although the inefficiency is probably exaggerated in a static framework.

ferent settings (Ruttan, 2002). Second, political and institutional settings also have variation, which has been unfavorable for developing countries. Paradoxically, whilst developed countries have continued subsidizing their agricultural sectors, developing countries have widely practiced taxation, either direct or indirect, of theirs. This empirically consistent positive correlation between per capita income and support of the agricultural sector is called the development paradox (de Gorter and Swinnen, 2002). Although detrimental to developing countries' agricultural productivity, taxation of agriculture has been an important source of government income in the absence of other plausible sources. Unfortunately, taxation has also increased food prices, further disadvantaging the poorest.

Johnson (1973, 1987) argued that the development paradox has had substantial spillover effects in global agricultural markets, resulting in a disarray in world agriculture. In effect, agricultural policies in both developed and developing countries have contributed to thinner and more volatile international markets for agricultural products, with detrimental welfare consequences, especially for the poorest nations (Anderson, Rausser, et al., 2013). However, there is some evidence of ongoing change. Anderson, Rausser, et al. (2013) show how developing countries' aggregate nominal rate of assistance (NRA)[31] started from negative values ($\sim -30\%$) in the 1950s and gradually increased after that reaching positive values in the 1990s. Meanwhile, the aggregate NRA figures for high-income countries started at positive values ($\sim 20\%$) and were on a growth trajectory in the 1950s, but peaked in the 1980s at $\sim 50\%$, since when they have steadily declined. Thus the NRA time series for high-income countries seems to exhibit an inverted U-shape. As a result, the difference between developing and high-income countries' NRA has decreased from a consistent 50 percentage points in 1950-1990 to 10 percentage points in the 2010s. Thus the trends in public agricultural spending between developed and developing countries are currently in line with a reversal of the development paradox. In general, this reversal coincides with disappearing disarray in world agriculture as developing countries have gradually gained a larger share of international agricultural markets (Alston and Pardey, 2014). Nevertheless, significant variation by countries, commodities and policy measures still exists.

The economically unintuitive development paradox has attracted a considerable amount of political economy research.[32] The dynamics between various interest groups are offered as an overarching explanation of the anomaly. Roe (1995) showed that the paradox could be explained by households' net market surplus and net labor market positions in a political economy model of heterogeneous households lobbying government. A related literature has tried to identify the preconditions for the ongoing change. Harvey (2004) argues that the modernization of agricultural sector is a favorable precondition for liberalization. Olper et al. (2013) showed empirically that democratization decreases taxation, and increases subsidizing of agriculture.

[31]NRA is the World Bank's measure of agricultural support and equals the gap between a current domestic price and a corresponding, hypothetical price under free markets.

[32]See e.g. de Gorter and Swinnen (2002) and Anderson, Rausser, et al. (2013) for surveys.

Right-wing governments are associated with subsidizing agricultural production, while left-wing governments are associated with directly supporting farmers' income levels (Anderson, Rausser, et al., 2013). Relatedly, the diminishing importance of agrarian parties is pre-requisite to liberal agricultural policy reforms (Harvey, 2004).

In industrialized countries agricultural issues have typically earned a special place among public policies, and they have become compartmentalized and characterized by producer-centered measures. The term agricultural exceptionalism was coined to illustrate the special role of agriculture, which was not subject to the ideals of free markets even in otherwise liberal countries (Coleman et al., 1996; Skogstad, 1998). Additionally, as claimed by Harvey (2004), the common approach of partial equilibrium, sectoral analysis of agriculture leaves much positive economic justification outside of agricultural policy analysis. A general equilibrium framework that better incorporates sector-specific factors such as land would be a more relevant basis for the analysis. Nevertheless, the agenda has gradually started to broaden in the 21st century[33] by interlinking to other domains such as consumer welfare and environmental concerns, among others (Daugbjerg and Swinbank, 2012). Daugbjerg and Feindt (2017) claim that as a consequence of increased liberalization pressures, food and agricultural policies might be experiencing a shift from an exceptionalist to a post-exceptionalist policy framework, where broader interest groups come to interact in defining policies.[34]

The World Trade Organization (WTO) and its predecessor, the General Agreement on Tariffs and Trade (GATT), have been important drivers in the development towards post-exceptional agricultural policies. In the process, the US and the EU have been the main protectionist groupings, with a rather reluctant movement towards trade liberalization in agriculture. The Agreement on Agriculture (AoA) in 1995 was a result of the GATT Uruguay round, and it agreed upon significant reductions in tariffs and non-tariff barriers to trade, export subsidies and domestic support. Under the agreement, the domestic support was to be decreased only in categories that were found to distort trade (the so-called amber and blue boxes), while subsidies with only a minimal effect (green box) were not affected. As a result, a developed countries have started to shift their domestic support to the green box by decoupling their payments from production. The US implemented decoupling in its 1996 FAIR Act reform, which moved the majority of domestic support to the green box. The EU's progress was more modest, and its first post-Uruguay round reform in 1999, Agenda 2000, merely shifted subsidies from the amber box to the blue box. In order to secure its position in the WTO's ongoing Doha round negotiations, the EU decided to turn its Agenda 2000 "mid-term review" into a full reform in 2003. In the Fischler reform the EU decoupled the majority of its CAP payments from production. Decoupling in the CAP context was implemented by establishing a so-called Single Payment Scheme (SPS). In SPS, farms are entitled to an area-based payment that does not

[33]The timing is of course imprecise. Skogstad (1998) puts the start in the US in the 1990s (FAIR Act in 1996), while the EU's efforts were lagging behind at that time.

[34]The NRA analysis by Anderson, Rausser, et al. (2013) lends some support to the claim of an ongoing policy shift.

require crop cultivation. In order to be eligible for subsidy payments in the SPS, farms need to meet so-called cross compliance requirements, which aim to establish minimal environmental, public and animal health, and animal welfare standards for agricultural practices. Thus the Fischler reform was a major step by the EU towards post-exceptional agricultural policies. Subsequently, the "Health Check" reform of 2008 continued the trend by further decoupling some of the remaining coupled payments.

Decoupling has become an intensively debated issue in agricultural economics. Policy-makers expect that decoupling will secure the compatibility of supporting domestic agricultural production and the advancement of multilateral trade negotiations. Urban et al. (2016) show that the predictive analysis by economic models are very sensitive to assumptions on the degree of decoupling. Unfortunately, the already vast literature on the degree of decoupling is very inconclusive.[35] Theoretical work has identified several channels that could undermine the promise of non-trade-distorting agricultural subsidies: e.g. risk and wealth (Hennessy, 1998; Koundouri et al., 2009; Femenia et al., 2010; Just, 2011), discouragement of exit decisions (Key and Roberts, 2006; Kazukauskas et al., 2013), incentives to invest (Vercammen, 2007), succession decisions (Mishra and El-Osta, 2008), credit constraints (Mishra, Moss, et al., 2008), off-farm labor opportunities (El-Osta et al., 2004; Key and Roberts, 2009) and portfolio choice (Chambers and Voica, 2017). Empirical work generally finds that decoupled payments have modest effects on production at most. Goodwin and Mishra (2006) found that the distortions from decoupled payments are very modest. Weber and Key (2012) did not find evidence of decoupled payments affecting production in the US. Chambers and Voica (2017) found that when decoupled payments are considered as part of a farm's portfolio choice, payments are in principle decoupled. However, the authors concede that the current practice of decoupled payments might not comply with the suggested idealized situation.

Although decoupling is central to recent developments in agricultural policies, its effects on land use are uncertain. Decoupled payments are usually associated with the policy incidence problem - although farmers are the recipients and the only target group of such support, a large share of the benefits could accrue indirectly to other parties, e.g. landowners via capitalization. The capitalization of agricultural support to land values was recognized well before efforts to liberalize agricultural trade (e.g. Wilcox (1964), Chryst (1965), Floyd (1965)). The rationale is that as subsidies increase demand for land, the prices and rental rates of land ought to increase.[36] Decoupling and incidence are related phenomena. Area-specific income payments are in principle more likely to have a lower incidence than coupled payments due to their direct relation to land. Some empirical studies have established a positive correlation between decoupling and low incidence, e.g. Patton et al. (2008), Kilian et al. (2012), and Ciaian et al. (2018). On the other hand, O'Neill and Hanrahan (2016) found a negative correlation.

[35] See OECD (2001) for a conceptual overview, and Bhaskar and Beghin (2009) for a review of the evidence, and Moro and Sckokai (2013) for a review of the remaining challenges.

[36] See Latruffe and Le Mouël (2009) for a review of the literature.

Additionally, Goodwin, Mishra, and Ortalo-Magné (2003) showed empirically that the effects could vary significantly by region. However, the degree of incidence is affected by the degree of decoupling, which also poses challenges for empirical identification (Roberts et al., 2003). Empirical evidence has found only partial incidence on landowners. Kirwan (2009) found that 25% of payments benefit landowners, with the remainder left for farmers (i.e. high incidence). On the other hand, inertia in land markets could distort the analysis. For instance, Hendricks et al. (2012) found that the estimated incidence was 12% in the short run and 37% in the long run. Kirwan and Roberts (2016) found that taking into account plot level variation increased the incidence. Towe and Tra (2012) exploited a differences-in-differences setting in the US ethanol mandate and found that the mandate had an effect on farmland prices. Ifft et al. (2015) found that an additional dollar of decoupled payments increased farmland prices by 18 dollars per acre in US. Hennig and Latacz-Lohmann (2016) found in a quasi-experimental setting based on German biogas feed-in tariffs that 61-140 euros/ha of rental rates could be explained by feed-in-tariffs. Graubner (2018) showed that a model that takes into account spatial competition predicts the partial incidence on landowners found in the majority of empirical work.

As mentioned earlier, agricultural land use is related to several externalities that render the free market solution sub-optimal in many cases. Therefore, some public and international intervention could be warranted in order to ensure sustainable land use. To that end, some coherent view of the effect of current agricultural policies on land use is needed. Climate change mitigation and biofuel production are new items on the agricultural policy agenda that directly link to broader land use issues (Daugbjerg and Swinbank, 2012). However, agricultural policy goals do not explicitly include directing land use in a socially desirable direction. The recent decoupling of agricultural subsidies from production in both the US and the EU has possibly decreased overproduction and distortions to international trade. It has contributed to land sharing, with some incentives for land set-aside and other measures that support extensive production methods like organic farming. Overall, Stoate et al. (2009) consider the land sharing elements in the recent CAP reforms to be positive developments for European nature conservation. However, essay II showed that decoupling has been detrimental for land sparing, which would have been a more desirable outcome from the sustainability perspective.

Land value tax is not commonly included in the array of agricultural policy measures despite its general attractiveness among economists. As discussed earlier, taxation of agriculture has been common in developed countries. However, output is more often taxed instead of land. It could be argued whether that is related to ubiquitous problems with land degradation in developing countries: with inadequate fertilizing, more extensive agriculture is practiced at the cost of deteriorating growth potential. Skinner (1991) argues that the tendency to increase farmers' risks and administrational difficulties are the main deficiencies of land value tax in an agricultural context. In cases where land value tax is applied, agricultural land is also commonly exempted from it. The main target of land value taxation is to gain tax income from higher value-added sectors and decrease externalities like inequality and inefficiency. Kassahun

(2006) suggests that differential land taxation could contribute to achieving sustainability goals in agriculture as well. Kalkuhl et al. (2018) find using simulation modelling for selected developing countries that land rent taxation has substantial untapped potential for raising fiscal revenues with minimal deadweight losses. They also find that distributional concerns could be efficiently addressed by non-linear taxation models, while new technologies have significantly reduced the administrative difficulties that were previously considered a major obstacle. Land value taxation could also be a part of developed countries' agricultural policies. Myyrä and Pouta (2010) studied how different forms of land taxation could affect the land market in Finland. Better functioning land markets would alleviate the land ownership fragmentation problem that causes allocative inefficiencies. They found that temporary relaxation of taxation on the proceeds of a farmland sale (TTF) could generate more farmland turnover than higher real estate tax (RET). However, the study did not take into account the potential of RET to encourage environmentally sustainable land use. As I suggest in the second essay of the dissertation, a combination of taxation on land and food security premiums paid on cereal output could achieve the goals of EU agricultural policy without causing inefficient use of resources, and at the same time contribute to land sparing. Such a policy combination would be compatible with sustainable intensification goals without violating the polluter pays principle. Differential rates of taxation on different land use categories could be envisaged, e.g. total exemption for grasslands and higher rates for environmentally sensitive areas.

2.3 Agricultural policies in Finland

Before its EU accession in 1995, Finland practiced an independent agricultural policy. The Farm Income Act of 1956 formed the basis for supporting income levels for farming populations by fully compensating farmers for cost increases with administratively set target prices. The consequent overproduction required additional supply control policies and a limited use of export subsidies (Kettunen, 1992). Accession meant a radical change in the operating environment of Finnish agriculture because the country had to adopt the EU's Common Agricultural Policy (CAP). As a consequence, administrative price control of agricultural products was removed, and producer prices decreased by almost 50% (Kettunen, 1996). In addition to this reduction, uncertainty in prices became a new factor to which Finnish farmers had to adjust. The food industry and retail sector had to adjust to more open competition from other parts of the EU single market. The reduction in producer prices was partly compensated by the adoption of CAP direct payments and an additional transitional support that was paid for the first five years after accession. The transitional support smoothed the inevitable income reduction and postponed the time when Finnish farmers reached the income level provided by the new policy regime.

Because the natural conditions in Finland differ greatly from the other EU countries, adoption of the CAP was predicted to cause a dramatic decrease in agricultural production (Törmä and Rutherford, 1993). In order to maintain an adequate agricultural sector for ensuring food self-sufficiency and to avoid major disruptions in rural communities, Finland negotiated an extensive right to pay additional national subsidies on top of the EU payments. Kettunen (1996) argues that the worst case scenarios were avoided perhaps due to these additional national subsidies. On the other hand Vaittinen (2004) estimates that because of the national subsidies, the farmers' income losses were actually over-compensated and farmers were net gainers of the accession.[37] Almost the whole country became eligible for Less Favored Area (LFA) payments, which were meant to be applied only in marginal agricultural regions such as mountainous areas. Only the southernmost region, subsidy region A, did not become eligible for LFA payments. However, the consequent income discrepancy between region A and the rest of the country was compensated by an increased rate of environmental subsidies in region A. Environmental subsidies, which are paid conditionally on participation in the Finnish Agri-Environmental Programme (FAEP), also became an unprecedentedly prominent part of agricultural policies in Finland. The accession negotiations enabled Finland to pay environmental subsidies to an extent that far overcompensates the costs of its take-up. Therefore the take-up rate has been untypically high, at around 80% of farmers and 90% of the total cultivated area (Siikamäki, 1996), almost irrespective of programme period.

In 1999, a further CAP reform, Agenda 2000, was agreed upon. The reform aimed to increase compatibility with WTO practices by further reducing administrative prices and harmonizing payments between crops. This reduction was again partly compensated with additional income subsidy payments. Finland was able to make some corrections to its accession agreement. Region A became eligible for LFA payments and the compensation in environmental subsidy rates was removed. The correction that shifted LFA and environmental subsidy payments among regions forms the empirical setting in essay III. The analysis was able to confirmed that area-based direct payments still significantly affect production decisions. The novelty in the analysis is that it can reliably establish the causal connection between subsidies and production decisions.

Essay II examines decoupled payments and how they have affected structural change in the Finnish agricultural sector. The empirical analysis shows that decoupled payments increased the more market-oriented farms' share of output. However, the land market became more rigid as the SPS made land ownership a form of income. The increased rigidity in the land market could be an indicator of increased incidence to land-owners, although the study is only suggestive in this matter. Also, the effect on the land market was found to be more dominant, and thus the reform increased net market inefficiencies. Overall, the shift from coupled payments to decoupled payments did not have dramatic consequences for sectoral output.

[37]National subsidies remain an important part of Finnish agricultural policy today. In 2017, EU agricultural support in Finland amounted to 1,418 million euros, of which 46% was nationally financed. On top of that, 330.9 million euros were paid as national aid. Thus in total 56% was financed nationally (Niemi and Väre, 2018).

2.4 Land use in Finland

According to FAOSTAT (2017) statistics, the total land area of Finland is 303,000 square kilometers. Forests dominate Finnish land use as forest ecosystems comprise 71.3% of total land use.[38] This share is the highest among the EU member states, where the average is 41.9%. The share of agricultural land is 7.5%, which is among the lowest in the EU. Almost all Finnish agricultural land is arable land with permanent crops and grassland comprising only 1.6% of the total. Although the number of farms has steadily decreased, agricultural land use has remained relatively stable. Since the beginning of EU membership in 1995, the area increased by 1.3% in 20 years.

In general, Finland is an outlier in European land use as it is characterized by a relatively high share of forests and a low share of agricultural land. Thus it is not obvious whether land sparing would be an optimal policy goal in the Finnish context. In biodiversity terms, agricultural landscapes might contain significant preservation values. For instance, Luoto et al. (2003) show that the land sharing elements of EU agricultural policies have been beneficial to agricultural biodiversity. In the EU, agricultural biodiversity is measured by the share of high nature value (HNV) farmland.[39] Paracchini et al. (2008) estimate that 45% of Finnish agricultural land can be considered HNV farmland, whereas the EU average is 32%. Finland was also identified as one of the regions with a high risk of land abandonment by Keenleyside and Tucker (2010) and Terres et al. (2015). Renwick et al. (2013) studied the effects of the recent CAP reforms on trends in land abandonment using large-scale economic and physical environment models, but were not able to find significant effects. This finding is line with essay II, which found very limited effects from the decoupling reform.

Its location in a northerly temperate climate is determinant for the carbon content of Finnish land: a high density of soil organic carbon (SOC) and a relatively low density of biomass (Scharlemann et al., 2014). Thusd the majority of carbon is stored in soil rather than in biomass.

The effects of agricultural policies on land use have been little studied in Finland. A notable exception is Pyykkönen (2006), who found that agricultural policies explain some of the price variation in the Finnish agricultural land market. However, this study also found that regional variation plays a significant role in the structure and structural change of agriculture. The study therefore confirmed that agricultural policies affect land prices directly and indirectly.

[38]The figures presented here are from FAOSTAT (2017) and they correspond to the latest available year (2015) unless otherwise stated.

[39]See European Environment Agency (2009) for the definition.

3 Economic theories

The empirical work in this dissertation is based on economic theories.[40] Essays I and III are based on what could be labelled as canonical, or neo-classical economic theories, which can be considered the prevailing, mainstream approach. Essay II, on the other hand, is based on evolutionary economic thinking, which can be considered a heterodox approach. This approach has a much less developed analytical and empirical basis, and therofore the essay also aims to contribute to advancing the empirical analysis within evolutionary economics. Subsection 3.1 summarizes the canonical economic theories and their relevance in this research, while subsection 3.2 does the same for evolutionary economics.

3.1 Canonical equilibrium economics

Canonical economic theories commonly apply maximization assumptions and equilibrium conditions as the *modus operandi* in order to make inferences on economic phenomena.[41] The origins of such theories are commonly thought to be in Walras (1896), and they were later formalized by Arrow and Debreu (1954) as the general (or competitive) equilibrium model.[42] The starting point for such a model is an allocation of resources between market participants, i.e. agents. In the model, the agents maximize their utility by trading their resources with other agents. As equilibrium is attained, prices settle at market-clearing levels. The dynamics of reaching an equilibrium are still not well understood. Walras schematically proposed a central "auctioneer", who initiates a "tâtonnement" process that sets prices to adjust towards the equilibrium level, but that is obviously not a satisfactory explanation (see e.g. Gintis (2007)). The model by Arrow and Debreu (1954) assumes automatic adjustment of prices to the market-clearing level. However, Gintis (2007) has shown that a competitive equilibrium emerges in an evolutionary agent-based model with replicator dynamics that do not assume centralized price dynamics. That model has also contributed to bridging the gap between canonical and evolutionary economics. When demand equals supply, the agents choose their optimal market transaction as suppliers or demanders. Thus the equilibrium is also a Pareto efficient allocation of resources, i.e. the welfare of any agent cannot be improved by reallocating resources without causing welfare losses to another agent.

The model has some contentious normative interpretations, but it has nevertheless enabled the economy to be presented as a system of simultaneous equations. Effectively, this mathemat-

[40] This state of affairs has become less self-evident in the recent discussion on the "credibility revolution" in economics, where various strands of "non-theoretical" thinking have gained popularity. Section 4.2.1 also touches on this issue and its influence on empirical work.

[41] In effect utility maximization is the only behavioral assumption, which actually makes the equilibrium conditions redundant (Boland, 2017).

[42] A less general application of the framework is called partial equilibrium, which typically examines an equilibrium attained by a sector while the demand for its output is considered exogenous. This framework is reasonable when the exogeneity of demand is a plausible assumption.

ical formulation has allowed analytical and numerical modeling of an economy. Marshallian comparative statics is a central analytical technique which is the basis, either explicitly or implicitly, of a large part of economic inference. Comparative statics is essentially a comparison of various conceivable equilibrium states that are defined by a pre-determined set of endogenous variables. The equilibrium states differ by an exogenous variable,[43] and the comparison is based on their ranking by some welfare measure. Boland (2017, p. 17) argues that: "The careful application of the method of comparative statics analysis has been the primary basis of almost all of our understanding of the economy when equilibrium models are the basis for our explanations."

The comparative statics framework is applied in this study as well. In essay I an array of results based on the empirical equilibrium model are used as a justification for evaluating model-based predictions. In the essay the basic equilibrium state of a CGE model is perturbed by an exogenous variable. In two simulations the productivity of agricultural land and the amount of subsidies paid to the agricultural sector are the perturbed variables. In essay III a comparative statics analysis justifies the mathematical structure of the corresponding empirical model. The empirical analysis in the essay confirmed that the comparative statics model predicts farmers' land allocation decisions well in the case of altered subsidy rates.

3.2 Evolutionary economics

Evolutionary economics is a branch of economic thinking that bases its inference on general evolutionary theories. Thus the main focus is evolutionary change in economic systems. In contrast to canonical economic theories, evolutionary economics does not emphasize equilibrium as a useful concept for making inferences about economic phenomena. Rather, this more marginal school of economic thought can be seen as a reaction to canonical economic thinking, and it is sometimes considered the successor of the school of institutional economics.[44] Although highly critical of canonical economics, evolutionary economics remains much less developed both analytically and methodologically. Witt (2014) finds much confusion and incoherent strands of development in the field, but also some as yet unexploited commonalities with canonical thinking. He uses the definition of causality by Tinbergen (1963) as an illustrative case to explain the boundaries between the schools of economic thought: whereas canonical economics attempts to find proximate explanations to economic phenomena, evo-

[43]Putting it another way, equilibrium conditions are compared by assuming that the other factors stay constant, i.e. the "ceteris paribus" assumption.

[44]Occasionally, some economists belonging to the canonical tradition have paid respect to evolutionary thinking in economics, e.g. Samuelson (1992) and Tirole (2017). As mentioned earlier, the agent-based replicator dynamics model by Gintis (2007) merges both traditions. Effectively, in the model evolutionary thinking provides a more plausible explanation for the dynamics of attaining an equilibrium. Significantly, it does that by simultaneously lending credibility to the concept of an economic equilibrium. Thus the canonical and evolutionary views are not inherently incompatible. Indeed in the pioneering evolutionary economics article by Alchian (1950) their commonalities were more pronounced than their differences.

lutionary economics is more concentrated on ultimate explanations. For instance, aggregate productivity changes are usually treated as singular, exogenous factors in canonical economics, while evolutionary economics puts more emphasis on more fundamental drivers affecting the changes.

This dissertation includes an empirical application of evolutionary economic thinking, which is rather rare in this new field. In essay II, an evolutionary economics analysis based on replicator dynamics shows how distributional change in heterogeneous agents that have varying responses to incentives forms a basis for induced change in allocative efficiency. The empirical analysis of the model shows that it produces intuitive results and can give a more nuanced description of the changes in sectoral structure and their underlying reasons.

4 Data and methods

4.1 Data

Various datasets were used in this dissertation. All the econometric work is based on either farm or field-level data. In addition, the CGE model in essay I uses input-output tables for calibration. The data sources are administered by public authorities and their collection required no work on behalf of the author(s).

The primary data used in the essay I is the *Statistics on the finances of agricultural and forestry enterprises* dataset by the Finnish statistical authority, Statistics Finland. The data is based on tax register data, and it is augmented by a survey data of individual farms. The survey includes 1-3 consecutive observations of each participating farm, and therefore forms an unbalanced panel. The survey variables include detailed categories of farm expenses, incomes and capital items.[45] The data also includes a classification variable for lines of production, which enabled the production functions for each line of production to be estimated separately. The data includes the years 2004-2009. The data was supplemented by working hours data from the *Structural farm survey* data by the Information Centre of the Ministry of Agriculture and Forestry (TIKE). Working hours were available for the years 2005 and 2007 only and the missing values were imputed.[46]

The input-output tabels used in the CGE model are derived from the *National accounts* data by Statistics Finland. The publicly available input-output tables include agriculture only as an

[45]The survey variables were required for the model used in this essay. Thus the model structure precluded the use of complete data in this essay. The model structure could also have accommodated the more commonly used Farm Accountancy Data Network (FADN) data. The advantage of the FADN data would have been a richer set of variables and standardized quality requirements. Its disadvantages with respect to the data that was actually used are the smaller amount of observations and possible selection issues of participating farms not being representative of average farms.

[46]The imputation applied a multiple imputation technique. Without imputation, a much smaller set of observations would have been available, which would have decreased the power of the analysis. However, the imputation could also have introduced bias into the estimates.

aggregated industry. Thus more disaggregated input-ouput tables were produced by using cost structures and shares derived from the primary data set. Both the empirical and the modeling parts of the study distinguished eight lines of production in agriculture.

Essay II uses register data of all Finnish farms. The dependent variables were constructed from farm-level observations of farms' market returns and agricultural land used. The explanatory variables were constructed from farms' market returns, variable costs and subsidy payments received. Covariates from the same data set include agricultural land used, investment expenditures, debt-to-asset ratio, dummy for exit, and farmer's age. Additionally, the variable of growing season length for controlling weather conditions was derived from Finnish Meteorological Institute's data merged with data for the nearest farm. The analysis used only the subset of grain and oilseed farms. The years included are 2004-2013, of which 2004 and 2005 are pre-reform years.

Essay III uses field-level register data for each Finnish farm administered by the Agency for Rural Affairs. The data includes farmers' cultivation decisions by field, i.e. the field area and cultivated crop. The data also includes various regional and farm level control variables, e.g. the field's owneship status (rent or own), municipality and subsidy region, subsidy payments received by category, forest area, and farmer's age. In addition, crop-specific subsidy rates by region and year were constructed from publicly available resources by the Ministry of Agriculture and Forestry. An additional variable for the setaside requirement that was used as a control was derived from data requested separately from the Agency for Rural Affairs. The analysis used only the subset of grain and oilseed farms. The years included are 1997-2002, which include three years before and after the implementation of the Agenda 2000 reform in 2000.

4.2 Quantitative methods in economics

Economic analysis applies both inductive (economic theories) and deductive (quantitative analysis) approaches. This dissertation belongs firmly to applied economics, and therefore applies the latter approach only. The quantitative analysis exploits an array of methods. The methods applied can be divided into two main categories: econometrics and numerical methods, which are both represented in this dissertation. The econometrics is applied statistics, whereas the numerical methods apply varying approaches from applied mathematics, operations research, and computer science. This subsection briefly introduces the methods applied in this dissertation.

4.2.1 Econometrics

Econometrics is a branch of statistics that is applied to economic questions, and it is the most commonly used quantitative approach in economics. However, a multitude of divisionary lines can be found inside the discipline. At the fundamental level of statistics, we can find a division into frequentist and Bayesian, or subjectivist, approaches, of which the former can be considered the mainstream approach (Poirier, 1988). The Bayesian approach is a generalization of the frequentist approach as it can readily incorporate a diverse array of probabilistic information. Most importantly, it can systematically make use of *a priori* information that complements the data. Conversely, the frequentist approach derives inference from the data only, although Bayesians respond that frequentists merely do not make their *a priori* assumptions explicit. However, computational demands and the arbitrary nature of evaluating varying *a priori* information have precluded the Bayesian approach from becoming more widely practiced.

The frequentist tradition has recently seen a deepening division between structural and non-structural approaches.[47] This division can also be seen as an argument on the appropriate use of *a priori* information: the non-structural approach finds little use for structures derived from economic theory and seeks to derive all the inference from observational data by an appropriate research design. The latter employs single-equation, linear models that exploit instrumental variables for identification. In contrast, the structural approach aims to estimate parameters in models derived by theory. The non-structural approach is the newcomer and its proponents argue for increased credibility of economic research. Heckman (2010) offers some vision for combining the seemingly opposing approaches.

The essays in this dissertation illustrate various applications of diverse econometric approaches. Essay III includes a literature review on different approaches applied to a particular statistical model that illustrates how many of the approaches from different econometric traditions are compatible, and how practical reasoning should be decisive for the final decision between the approaches. Furthermore, the empirical analysis in essay I is based on a simple structural model, while in essay III a non-structural model is estimated. Essay III also draws a comparison between the non-structural and structural approaches by applying both approaches in the same problem.

Econometric analysis is always based on observational data, and the aim is to estimate parameter values to answer an empirical question. Thus econometric work is primarily *ex post* analysis, i.e. study of past events, or evaluation of policies. Econometrically derived parameter values could also have a role in constructing predictive economic models.[48] All the econometric work in this dissertation is *ex post*. For instance, in essay I agricultural production functions are estimated. The parameters are needed for deriving substitution elasticity estimates, which answer the question: how easily can one input be substituted for another in production? Essay I aims to find how other inputs can be substituted for land, i.e. to what extent the intensive margin of land use can be expected to change with current evidence. The aim of the analysis is to find the average effects in the population. In contrast, the aim in essay II is on the distributional level: what are the effects of a policy change on some distributional properties of the whole sector,

[47]See e.g. Deaton (2010), Leamer (2010), Nevo and Whinston (2010), and Sims (2010) for the merits of the structural approach, and Angrist and Pischke (2010) for the merits of the non-structural approach.

[48]Statistical learning or machine learning methods have recently also gained interest in predictive econometric analysis. See Mullainathan and Spiess (2017) for an introduction and Hyvärinen (2016) for an application for predicting structural change in Finnish agriculture.

i.e. has decoupling policy increased market orientation in input or output markets and is there distributional variation in the responses? The essay applies quantile regression techniques as introduced by Koenker and Bassett Jr (1978). Essay III aims to find a causal connection between a policy measure and production decisions. That is achieved by exploiting a quasi-experimental setting which coincided with a policy reform.

4.2.2 Economic modeling techniques

Although econometric techniques could be applied in prediction, many economic issues are structurally too complex for such an approach. In those cases economic modeling techniques have proved useful. The models come in several types, and can be placed in two main categories: 1) equilibrium models like partial equilibrium (PE) models for the analysis of separate sectors, computable general equilibrium (CGE) models for analysis of the whole economy with industrial detail,[49] and dynamic stochastic general equilibrium (DSGE) models for analysis of the whole economy with forward-looking dynamics and uncertainty; and 2) statistical and disequilibrium models like micro-simulation (MS), and agent-based models (ABM).[50] The equilibrium models are closely associated with canonical economic theories, while the disequilibrium models are mainly applied in non-canonical economics, e.g. evolutionary economics. In essence the models are computational presentations of economic theory calibrated with observational data and parameter estimates. Thus economic modeling techniques have an advantage in many *ex ante* questions.[51] For instance, models of complex interactions of land use and economies require a modeling approach. Therefore, as noted earlier, the assessment of climate change mitigation and biofuel policies are both based on economic modeling work. Although economic modeling is more theory-driven, *ex post* econometric work is also needed in order to calibrate the predictions with observed behavioral quantities, e.g. elasticities. In essay I, CGE model calculations are evaluated by their choice of functional form. The models are parameterized by empirical estimates from the same essay. The essay illustrates how these two approaches are complements by presenting an example of extending an econometric analysis with CGE model analysis.

5 Essays in the thesis

This section includes short summaries of each essay in the dissertation and their main findings.

[49]See Hertel (2002) for a review of CGE model applications in agricultural and resource policies.

[50]See e.g. Happe et al. (2006) for an ABM application in agricultural policies, and D. T. Robinson et al. (2007) in land use modeling.

[51]The division is not completely clear-cut. For instance, CGE models could also be suitable, although rarely used, for *ex post* policy analysis. See e.g. Williamson (1990) for a CGE analysis of the repeal of the Corn Laws in 1846.

5.1 Essay I: Intensive margin of land use in CGE models - Reviving CRESH functional form

The essay (Simola, 2015) examines intensive margin adjustments of land use in agriculture. The modeling of land use is an important part of the analysis of the agricultural sector by itself and in its relation to the environment. Analysis of global greenhouse gas emissions, climate change, and projections of food security can be informed by global economic (partial or general) equilibrium or impact assessment (IAM) models. Additionally, land use projections have increasingly come to rely on computable general equilibrium (CGE) models due to their flexibility in incorporating aspects like varying sources of demand and physical characteristics of land in their framework (Hertel, Rose, et al., 2009). Baldos and Hertel (2013) show that economic models outperform biophysical models in their accuracy of predicting land use change. Furthermore, they find that biophysical models are likely to underestimate land use change. Schmitz et al. (2014) survey equilibrium modeling studies on land use change and find that the majority of models predict a 10-25% increase in cropland by 2050 (compared to 2005). The authors end up recommending more emphasis on (supply) elasticity estimates and overall model validation. Thus far the analysis of land use has concentrated on extensive margins, for instance the allocation of land between agriculture and other activities like forestry. In global CGE models the most common intensive margin specification applies the constant elasticity of subsititution (CES) functional form with varying nest structures (S. Robinson et al., 2014). However, only some of the models assume explicit substitution of land in a nested CES function. Furthermore, Hertel, Baldos, et al. (2016) found that intensive margin adjustment ranks as the second highest source of uncertainty in CGE model land use predictions, the highest being the supply response of non-land inputs. Studies have shown that models that use estimated elasticities rather than literature values are better validated (Beckman et al., 2011; Wunderlich and Kohler, 2018). More recently, Suh and Moss (2018) showed with sector-level empirical analysis that farmers in the US adjust both their intensive and extensive margins as responses to price changes.

This study has further demonstrated that proper modeling of intensive margin adjustment is an important factor for model validity. Furthermore, this analysis empirically demonstrates the differences between various functional forms. The results show that the CRESH (Constant Ratios of Elasticity of Substitution, Homothetic) function that was originally suggested by Hanoch (1971), should be preferred over its less general versions such as CES. Comparison of the functional forms with a CGE model further demonstrates that the model results are not invariant to the functional form.

The study used farm-level microdata in its empirical part. Estimation of the agricultural production function allowed a set of nested functional forms to compared: Cobb-Douglas, non-nested CES, the three variants of the nested CES functions, and the CRESH function. Two factor compositions were analyzed separately: capital, labor and land (all the functional forms), and capital, labor, land and fertilizer (CRESH only). The analysis showed that the CRESH outperformed the other functional forms. The estimations were conducted for six separate lines of production: beef, dairy, grains and oilseeds, pork, poultry, and other plant production.

In order to assess the performance of the estimated functional forms in an actual economic model, two simple CGE simulations were performed with a static CGE model–the ORANI-G (Horridge et al., 2000).[52] First, an exogenous improvement in the productivity of land, and second, an exogenous reduction in farm subsidy payments.[53] In all of the cases, the functional forms were parameterized with empirical estimates. Both simulations showed that the results are sensitive to the choice of functional form. In general, the preferred (but rarely used) CRESH functional form predicts intensive margin adjustment that differs from those produced by the commonly used nested CES functional forms. The two simulation exercises display different adjustment capabilities for different shocks: the CRESH predicts more adjustment to policy changes, and less adjustment to productivity changes.

5.2 Essay II: Government payments, market profits and structural change in agriculture

This essay empirically evaluates how the structure of the agricultural sector responds to incentives from the markets and public sector income transfers (i.e. agricultural subsidies). A novelty in this study is to allow heterogeneity among farms in their response to these two forms of income. The question is relevant because public intervention in agriculture has shifted toward decoupled income payments that supposedly affect production decisions only minimally. This study evaluates whether and to what extent the EU Common Agricultural Policy (CAP) reform of 2003 affected the production decisions of Finnish farms. The reform decoupled agricultural income payments from production by changing crop-specific CAP payments into Single Payment Scheme (SPS) payments that are not dependent on (current) yields or cultivation decisions. The stated goal was to make the sector more market-oriented by removing crop-specific payment rates. At the same time land ownership became a form of income with the possibility of creating rigidities in land markets. From the outset, it is ambiguous which effect dominates.

The study applies the replicator dynamics framework, which allows distributional change

[52]The ORANI-G simulations applied the short-run closure characterized by fixed capital demand. Although long-run closure is more widely used in static CGE analysis, it assumes adjusting capital use, and has therefore equal outcome for each of the production function specifications. Thus long-run closure would have been ill-suited for the comparison of functional forms that was the aim of this study. In addition, short-run closure emulates the expected differences in dynamic CGE models well without confounding the comparison with assumptions required for a dynamic model baseline.

[53]The specification of subsidy payments included the total subsidy receipts of the production lines. The exercise therefore abstracts from various forms of subsidies, e.g. coupled and decoupled subsidies, and varying distribution of these among lines of production. However, essay II of this thesis finds little difference between coupled and decoupled subsidies.

in a sector to be assessed. The empirical assessment is based on Fisher's principle, as suggested by Metcalfe (1994). The principle is in effect an application of general evolutionary theory, which already has some applications in economics (e.g. Metcalfe and Calderini (2002) and Cantner et al. (2012)). The model explains changes in the market shares of individual farms with so called fitness factors. The study is the first economics application of the principle that simultaneously evaluates two fitness factors, namely incomes from two separate sources, markets and government payments. Furthermore, the study evaluates the effects on both output and land markets, and finds that the effects differ significantly.

The empirical part utilizes the quantile regression method developed by Koenker and Bassett Jr (1978), which allows the effects on the whole distribution of the studied population to be examined rather than merely the average effects, which could hide underlying non-linearities. For instance, the farms at the lower end of the growth spectrum could respond to subsidies very differently from those that have grown the fastest. Indeed, the empirical results show that the average effects are clearly not a complete picture of the evolution of the sector. In general, subsidies are a more important determinant of farms' distributional success than market income, although evidence for both market orientation and policy-related rent-seeking was found. The interaction between market and subsidy income is found to be negative, which means that they attenuate each other's effects. Therefore subsidies select farms with different characteristics than what pure market incentives would do. Unfortunately, the available data did not allow further investigation of these characteristics.

The policy reform helped the more market-oriented farms to increase their share of output markets, as was intended. However, the land market became more rigid, which is also in line with predictions. The latter effect was found to be dominant, and thus the overall goal of a more dynamic and efficient sector was not reached. In general, the effects of the reform were very small compared to the underlying effect of paying subsidies in the first place. In other words, receiving subsidies in one form or another explains much more of the sectoral structure than the implemented change in the means of paying the subsidies. The results also illustrate that although the EU's SPS payments are in principle decoupled from production decisions, they are not decoupled from land. A more radical form of decoupling, i.e. the bond scheme suggested by Tangermann (1991), could possibly achieve that.

5.3 Essay III: Production decisions and agricultural subsidies - evidence from a quasi-experiment in the Agenda 2000 CAP reform

This essay addresses the question of how responsive farmers' production decisions are to coupled income subsidies. More specifically, we study how crop-specific, coupled area payments affect changes in crop mixes. The production response to coupled support payments has not been studied in a setting as rigorous as in our analysis, where we exploited a quasi-experimental setting. Although the majority of income support in the EU is currently decoupled, the most recent suggestions for future reforms of the CAP suggest increased independence for member states and options for “re-coupling” of the income support (Niemi and Väre, 2018).

In our analysis, we exploited corrective measures to regional differences in crop-specific payments, which were conceived in the Agenda 2000 reform in 1999. The setting forms the basis for a standard differences-in-differences (DiD) analysis that makes it possible to identify the causal effect. In the reform the relative levels of crop-specific area payment ratios changed between regions A and B, and region A became eligible for Less Favored Area (LFA) payments. The most visible change happened to wheat, which became comparatively less favorable in region A after the reform. Simultaneously, the environmental subsidy rate decreased in region A compared to region B. With this setting we were able to control for unobserved heterogeneity, and time and location-specific confounding factors. That allowed us to confidently identify the causal effect of coupled subsidy payments on production decisions. In addition, we were able to estimate the subsidy elasticities of land use. Our data was comprehensive data for all Finnish crop farmers in regions A and B, three years before and after the reform (1997-2002).

Our empirical model is based on farmers’ decisions to allocate their land between various crops. The essay includes a comprehensive summary of the available empirical methods. Based on the literature, we needed to consider three main issues in the estimation strategy: 1) the dependent variable, the share of a crop in farmer’s crop mix, is a share and thus naturally restricted between zero and unity; 2) the error terms of the crops are likely to be correlated, which requires estimation of the whole system; and 3) farm-level heterogeneity needs to be adequately controlled. The conclusion is that of the three objectives only two can be addressed simultaneously with existing methods. Heterogeneity can be controlled by various means, although fixed effects estimation would be ideal. However, deciding to use the fixed effects model would preclude fulfilling both the dependent variable and correlated error terms conditions. An alternative–correlated random effects (CRE)–is available in more general models. As a robustness check, we decided to estimate a set of models. The fractional response model by Papke and Wooldridge (1996, 2008) allows for an explicit modeling of a limited dependent variable in a single equation framework with CRE control for unobserved heterogeneity. For comparison, the equivalent OLS with fixed effects model is also estimated. In order to assess the neglect of the correlated error terms in single equation models, estimations with a multinomial logit model were performed. The results with all the models lead to the same general conclusions, although minor differences were found as well.

Instead of estimating the whole structural equation of the farmer’s land allocation problem, we conducted a reduced form estimation similar to Fezzi and Bateman (2011), where we were able to control for price and output variation with region-year dummies. The method is flexible and does not require data as detailed as the full structural equation estimation. We used register data for all the Finnish farms that included only their cultivation decisions by plot, plot location at municipality level, and a set of control variables for farm heterogeneity: farmer age, share of rented land, forest area, setaside obligation, and subsidy payments received by farm and subsidy payment category.

The results showed that the DiD coefficients were significant for wheat, rye, oilseeds and setaside. All the significant coefficients have signs that largely conform with the theory. Thus we can conclude that farmers adjust their production decisions to coupled subsidy payments, as predicted by theory. The cultivation of wheat, which had the most pronounced regional subsidy rate shift, decreases in region A in relation to region B. We estimate that the effect of the policy reform for wheat cultivation was a 3-6% points reduction in region A. Other crops did not experience such clear regional subsidy rate shifts, but nevertheless had siginificant DiD coefficients in line with the theoretical predictions. The other crops that did not receive any payments adjusted too, due to changes in the overall composition of the crops cultivated.

We were also able to calculate the elasticities of different crops to subsidy payments. Most of them are significant and elastic in the single equation fractional response model. Less risky crops like feed barley and oats have higher subsidy elasticities (13.0 and 12.4, respectively) than higher-risk crops like wheat (2.3). The elasticities from the multinomial logit model are very similar: 1.7 for wheat, 14.5 for feed barley, and 17.1 for oats.

6 Discussion

This dissertation has analyzed the connection between agricultural policies and land use. The findings could contribute to the assessment of land use changes that relate to two broad policy issues: 1) climate change and its mitigation in agriculture, and 2) agricultural policy reforms. The three essays included in the dissertation highlight diverse points in this vast set of issues.

Essay I contributes to the modeling of the intensive margin of land use by offering some evidence on the choice of the functional form that could improve land use predictions in economic equilibrium models. The empirical estimates indicate an inelastic intensive margin response. Nevertheless, the results suggest that a more general functional form like CRESH is likely to predict a better adaptation to policies and climate change in the agricultural sector. Conversely, the widely used CES functional form is likely to underestimate the intensive margin adjustment and thus overestimate the costs of the adaptation. However, as the analysis is based on Finnish data, the results cannot be readily generalized e.g. to global models. Thus an analysis that compares the choice of functional forms in global economic models is needed for more general conclusions. The same applies to the empirical estimation of the production function, which would improve the empirical basis of the models. It is also unclear how the ranking of various climate change mitigation options would be affected by a more careful modeling of the intensive margin of land use. Nevertheless, the results further vindicate the use of economic models with adequate sectoral detail such as CGE models, because they can readily incorporate various intensive margin specifications. The study also illustrates the importance of empirically derived elasticity parameter values.

Essay II shows that farms' responses to policy changes are heterogeneous. Farms' responses in both land use and output distributions are affected by income coming from both markets and government, although the latter explains more of the variation. Decoupling of income payments increased farmers' flexibility in choosing their product mixes. Farmers who are more market-oriented benefited from the increased flexibility. Decoupling also increased rigidities in land markets, which has led to allocative inefficiencies. Increased land market inefficiency was higher at the median value than the benefits brought by increased market orientation. Therefore the net benefit of the reform was negative. Nevertheless, the form of subsidy payments mattered relatively little in comparison to the overall effect of the subsidy payments received. Still, it is evident that decoupled payments have encouraged inefficient forms of land use, which might nevertheless have some benefits if land sharing is held as a policy objective. Although in general the evidence does not favor land sharing as a global solution, the Finnish case could reasonably be seen as an exception with its low share of agricultural land, which is associated with substantial biodiversity. The essay also demonstrated that although replication dynamics models based on Fisher's principle are novel and thus far rarely applied, they yield economically intuitive results. The two main outcomes increased market orientation and increased land market rigidities could be predicted by neoclassical economic reasoning. Furthermore, quantile regression proved to be an appropriate empirical strategy, as it naturally incorporates distribution-wide implications. The framework has some potential, but it nevertheless needs to be applied more widely before its suitability to diverse settings can be demonstrated. One issue yet unexplored is the application of Fisher's priciple in predictive analysis, to which it could add more nuanced non-linear features.

Essay III found that the coupled area-based subsidy payments affect farmers' land use decisions directly. The observed changes are mostly as predicted by economic theory. The result has a causal interpretation due to the quasi-experimental setting of the study. Farmers seem to substitute between crops with a similar risk as the reduction in wheat cultivation was mostly compensated by increased cultivation of rye and oilseeds. The estimated elasticity values are very high, and therefore subsidy payments have a disproportionate effect on cultivation decisions. The disproportionate effect could be explained by risk-aversion - changes in the risk-free component of income, i.e. area-based payments, have a larger effect than uncertain market income. Riskier crops were found to be less subsidy-elastic. The results also suggest that a further reduction in coupled subsidies is a reasonable goal in order to decrease trade distortions. On the other hand, as shown in essay II, decoupling, at least in its current form in the EU, has not changed the situation much. Decoupled payments remain controversial, and a comparison of decoupled payment elasticities to coupled subsidy elasticities as estimated here is a potential future direction of study. The differences-in-differences setting was a feasible approach in this study due to the idiosyncratic corrections made to the Finnish accession agreement in the Agenda 2000 reform. Nevertheless, such quasi-experimental settings are rare. Therefore, in order to improve and further accumulate the empirical evidence of farmers' responses to agricultural policy changes, agricultural policy reforms could start to incorporate real experiments. That would also contribute to more accurate predictions of land use changes in agriculture.

All the essays have applied different methods in order to highlight different aspects of the phenomenon. The conclusions of the essays mostly support and complement each other. Essay I defines farmers' intensive margin adjustment possibilities empirically, and shows that this adjustment should be taken into account in sectoral and general equilibrium models. The essay demonstrates that evaluation of agricultural subsidy payments by equilibrium models benefits from empirical elasticity estimates. Essay II shows that the distinction between coupled and decoupled subsidies has an expected but quantitatively minor effect on farmers' production responses. Essay III confirms that the effect that coupled subsidies have on production decisions is causal. Thus the essays II and III together suggest that decoupled payments might have an effect on production decisions after all.

Overall, the study has highlighted some issues that are relevant for advancing economic research of land use in relation to available policy options. All the essays are based on Finnish agriculture, which has several unique characteristics. The share of agriculture in total land use is relatively small in Finland. Finland is also located at the northern boundaries of climates that are feasible for agriculture. The need to direct land use in a more land sparing direction is well established in the literature. However, this objective has to be seen in both global and regional contexts. The Finnish case examined in this dissertation represents a case of relatively minor relevance for land sparing objectives. Conversely, there is a reasonable rationale for land sharing as currently encouraged by setaside and "greening" options to be part of Finnish land use policies. That of course does not mean that the extensive margin–allocation of land among agriculture and forestry–does not have to shift in future in order to better accommodate climate change mitigation goals. Ultimately, the results suggest that the policies perhaps do not serve the remaining EU equally well. In addition, the distinction between coupled and decoupled subsidies is minor in practice. Therefore, future agricultural policy reforms should consider more radical options than current decoupling. A "bond scheme" could be an option that would also decouple the payments from land use. As a result, both extensive and intensive margins could become more flexible to accommodate various policy goals.

7 Conclusions

This dissertation makes a contribution to current agricultural economics literature in several aspects. First, the study offers novel and diverse perspectives on the effects of agricultural policies on land use. Both coupled and decoupled subsidy payments are considered as policy options. The study sheds new light on intensive margin adjustment possibilities. Second, the dissertation has adopted an array of empirical methods: OLS, quantile regression, and CGE modeling. The variety of methods also contributes to the robustness and validity of the results. Third, the dissertation proposes meaningful conclusions and policy recommendations. For instance, decoupled payments increase farmers' flexibility in choosing their product mixes, which benefits more market-oriented farmers. On the other hand, the same subsidies increase rigidities in land markets, which has led to allocative inefficiencies. The conclusions have implications that could be helpful for designing future reforms of EU and Finnish national agricultural policies.

The objective of this study was to analyze the ways in which that agricultural policies steer land use decisions in Finland. The main concern is in reconciling various uses of land: production of food, fiber and wood, and ecosystem services like biodiversity and carbon sequestration. Two broad solutions are suggested in the literature: land sparing, which means more intensive use of existing land; and land sharing, which means increasing the biodiversity of current agricultural ecosystems. In addition, agricultural policy has its own objectives such as securing the income level of the farming population, which could conflict with other objectives. The study applied an array of theoretical approaches and (quantitative) methods.

Essay I found further evidence of the importance of intensive margin adjustment of land use in economic models. The choice of functional form matters too, and the CRESH functional form was the best fit empirically. The wider use of that particular functional form or other more general functional forms could yield more optimistic predictions of the adaptation of agricultural land use. Therefore, current models are likely to be somewhat too pessimistic about the costs of adopting more intensive agricultural practices. This study gives a reason to be more optimistic about the costs of land sparing solutions.

Agricultural income subsidies affect land use directly. Essay III shows that farms' land allocation is very responsive to coupled income payments. On the other hand, essay II shows that the distinction between a coupled or decoupled subsidy has little effect on the allocative efficiency of land compared to the effects of total subsidy income. Nevertheless, decoupling of income payments has increased rigidities in land markets and thus contributed to the allocative inefficiency of land. That inefficiency was partly compensated by improved market orientation in output markets. However, along with increased allocative inefficiency, decoupling has contributed to the land sharing solution.

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Product mix choice and agricultural subsidies - evidence from a quasi-experiment in the Agenda 2000 CAP reform

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Abstract

This paper examines the effects of coupled agricultural subsidy payments on farmers' production decisions. We exploit a quasi-experimental setting that emerged between Finnish agricultural subsidy regions in the EU Common Agricultural Policy reform Agenda 2000 in 1999. The uncovered variation catches the causal effect of coupled subsidies on planting decisions. The effects reflect the farmers' response to coupled direct subsidy payments.

Our empirical setting is a standard differences-in-differences model applied in the fractional response framework, which explicitly takes into account the non-linear dependent variable. We control unobserved heterogeneity with both fixed effects (linear specification) and correlated random effects (fractional response model). We were able to use a comprehensive, farm level micro data in our analysis.

We found that changes in payments to individual crops explain changes in crop mixes. The observed causal effect conforms well to theoretical predictions. Furthermore, the response was found to be very elastic. Estimated semi-elasticities are helpful in predicting the overall changes in crop shares.

JEL classification: C12, C33, Q12, Q18

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1 Introduction

Due to evident unfavorable comparative advantages, many industrial nations support their agricultural producers. The rationalizations include concerns over food security, rural livelihoods, and income level of farming population. As subsidies in general, agricultural payments have unwarranted economic costs. They are a fiscal burden that possibly maintains inefficient production. Furthermore, the subsidies distort international trade and thus affect developing nations' agricultural sectors and their food security. Consequently, international trade agreements have pursued to steer the policies in less harmful direction. In addition to directly trade related payments like export subsidies, the support measures of domestic production face pressures for reduction and modification. The development of agricultural policies in the past thirty years has seen increased emphasis on direct income support in contrast to subsidies coupled to actual output. So called decoupled subsidies are assumed to have only minimal effect on production decisions. Thus they are deemed acceptable by WTO.[1] Consequently, the EU's position in WTO was improved in 2003 Fischler reform by decoupling the majority of its coupled income payments. The EU further decoupled most of the remaining coupled income payments in the Health Check reform in 2008.[2] Thus coupled payments have become sparingly practiced in today's agricultural policies. However, the most recent proposal (The European Commission, 2018) for the EU's future agricultural policy reform have suggested more flexibility for the member states to design their agricultural policies including the increased use of coupled income support.[3]

In this paper we examine more closely how the assumption on coupled payments' effects on production decisions holds true when examined empirically. More specifically we aim to estimate the elasticities of land use decisions to coupled subsidy payments. Therefore, our results could shed light on the production effects of the future acts of re-coupling.

Empirical assessment of subsidies, coupled or decoupled, is wrought with difficulties as direct link between payments and production outcomes is not easily disentangled with observational data. Subsidies are not the sole factor affecting production. Farmers

[1]The actual definition of decoupled subsidies gives room for tailoring context specific policy mixes. It is sufficient that a mix of policies has "a zero net effect on equilibrium prices and quantities" (OECD, 2001).

[2]The member states were allowed to maintain suckler cow, goat and sheep premia coupled payments.

[3]The proposal suggests that the member states would be allowed to use "coupled income support specifically for improving the competitiveness, sustainability, and/or quality of the protein crop production", and have "an increased flexibility to set up the combination of both types of interventions in the form of direct payments, sectoral types of interventions and types of interventions for rural development" (The European Commission, 2018, p. 28).

also receive market income for which they have some expectation before planting decision. They also need to take into account related natural conditions and uncertainties that circumscribe the available decisions and affect the quantity and quality of output.

This paper exploits a quasi-experimental setting of the EU's CAP reform in 1999, the Agenda 2000. In the reform, two neighboring subsidy regions, A and B, were treated differently by their crop-specific payments to wheat. The differential treatment hinges on region A's ineligibility to pay so-called Less Favored Area (LFA) payments before the reform, and a related compensation with additional environmental subsidies. We could exploit this differential treatment as an empirical quasi-experiment. Our analysis exploits a comprehensive data of Finnish farmers before and after the reform. We found that farmers adjust their production to changes in coupled subsidy payments largely as predicted by economic theory. Furthermore, discovered response is very elastic. Thus coupled subsidies have very direct effect on planting decisions. We also found that crops with higher production risk (wheat and rye) are less elastic than crops with smaller production risk (feed barley and oats).

The rest of the paper is structured as follows. Section 2 summarizes the background of agricultural policies and farm production decisions. Section 3 summarizes the empirical data, empirical methods, and the strategy of inference. Section 4 presents the results and section 5 discusses them more broadly. Section 6 concludes.

2 Agricultural policies and farm decision making

Farmers need to make a set of nested decisions that together with random natural and market events define the outcome of planting season.[4] First, it needs to be decided whether to continue farming or to exit. In Finland–as in many other industrialized countries–the number of farmers that decide to continue has declined steadily. The factors affecting this development are the general profitability decline in agriculture and a comparative disadvantage in incomes to other occupations.[5] In case of continuation, the second decision is to determine the scale and the size of operation. This is restricted by typically low availability of land and farm labor in local markets, returns to scale (typically decreasing), and economies of size (typically increasing). Finally, there is the decision is to choose the mix of crops that are cultivated. This decision is influenced by farmer's risk preferences and available production factors like labor, as the crops differ

[4]This brief description relates to decision stages on a crop farm and thus ignores additional conditions and decisions encountered on animal farms.

[5]Consequently, also the number of farmers, who enter the business, is very small. In Finland farms are typically family businesses that remain in existence via generational succession.

in their yield-to-risk ratio and labor intensity.[6] Additionally, farms typically follow a longer term cultivation plan that assign fields with crop rotation rules. These rules might dampen farmers' incentives to adjust their production due to changes in prices and subsidies. Additional factors that could affect crop mix choice are decreasing returns to scale, risk spreading and investments in quasi-fixed factors other than land, e.g. machinery.[7]

Each decision stage could be affected by agricultural policies. Decisions of continuation and scale both require expectations of overall level of subsidy payments relevant to a region. Decision of a crop mix is only affected if the agricultural policy menu varies between crops. It could be argued that the shift toward more decoupled subsidies has decreased the relevance of agricultural policies at this stage. Additionally, a decision might be restricted by institutional requirements for e.g. a minimum amount of setaside land. The CAP regimes relevant to this study included a setaside obligation of 10% of cultivated land for large farms.[8,9] Voluntary setaside was also compensated by a direct area based payment, the setaside premium. The maximum area eligible for setaside premium is equal to the area devoted to crops eligible for area based payments. In addition, the farms could participate in agri-environmental programs (AEPs), which include restrictions to production practices and related compensatory payments. Finland has a particularly high uptake rates of the AEPs. A likely reason is that the accession agreement enabled over-compensation of the costs related to complying costs of the program.

The CAP itself is a fairly complex set of policies. The Finnish case has additional complexities of its own as Finland negotiated an extensive right to pay national subsidies in its accession process leading to the EU membership in 1995. Political complexities affect the farm-level decision making directly as the compliance to support payments requires extensive administrative reporting and compliance to surveillance measures. It could be argued that although the system increases available resources for production, at the same time it nevertheless complicates farmers' production decision processes

[6]See Koundouri et al. (2009) for empirical evidence of heterogeneous risk preferences among farmers.

[7]See Hennessy (2006) and Hendricks et al. (2014) for crop rotations as part of farm decision making, and M. Robert et al. (2016) for a more complete discussion on farm decision making with bio-economic constraints. Recently Bareille and Letort (2018) found evidence that farmers allocate their land among crops in order to benefit from increased biodiversity.

[8]Large farms are defined as having at least 92 tonnes of grain or sileage production.

[9]As an exception the setaside obligation was only 5% in Finland due on the transition period of EU accession in 1995-1997. In 1995-99, which was the transition period of the accession, the farms themselves selected their setaside practice; opting in required a minimal, uncompensated share of land to be setaside, whereas opting out meant foregoing the area-based payments altogether. Since 2000 an accounting prediction of output tonnes was applied to determine the category for each farm.

due to increased administrative burden.

The CAP has seen several reforms during Finnish membership era. The first was the Agenda 2000 reform agreed upon in 1999. It continued the MacSharry reform of 1992 by reducing the intervention price levels of agricultural commodities. The reduction was compensated with increased direct coupled CAP payments. The payments were differentiated by subsidy regions based on their historical yield levels. Thus previously more productive regions received higher compensations. Additionally, the CAP payments for major grain crops and oilseeds were harmonized.

The reform included a set of idiosyncratic policy changes in its Finnish implementation. The first change relates to the Less Favorable Area (LFA) payment. The Finnish accession agreement to the EU in 1995 claimed that the southernmost part of the country was favorable enough to be left out of the LFA subsidy, which was originally designed to alleviate disadvantaged agricultural conditions inside member states, e.g. mountainous areas. In the reform the natural conditions of the whole country, region A included, were reconsidered to be eligible for the LFA payment. The second change was that the cultivation of wheat in all the regions became also eligible for LFA payment. After the reform, the LFA subsidy was paid to all the cereals and oilseeds, but not to setaside. We can exploit these changes in order to identify a causal effect between crop-specific area payment and cultivation of that crop. The most distinct crop-specific change was with the total subsidy receipts to hectares cultivated with wheat, as they were 36 % higher in region A than in region B before the reform, but were harmonized after that.

The third change relates to the fact that the difference in regional LFA payments was compensated with a higher environmental subsidy rate in region A. That compensation was financed nationally by a special agreement. In the reform the compensation was eliminated when the environmental payments were harmonized between the two regions.

2.1 Land allocation problem

This section presents theoretical underpinnings of farmers' land allocation problem, which is relevant in our empirical analysis of the crop-specific payments. We closely follow the framework suggested by Chambers and Just (1989). In order to supplement their standard model, we adapt the treatment of area based payments and setaside premium from Guyomard et al. (1996), and normalization to land shares from Fezzi and Bateman (2011). The resulting model is convenient as it gives rise to an empirical model that has crop shares as its dependent variables. The crop shares is a good measure of production decisions as they are not subject to price and yield uncertainties accumulating throughout the year, which affect the actual output. They are also normalized with respect to farm size.

Land allocation can be approached directly by specifying crop yield functions, whereby farmers choose their land allocations based on expected yields, output prices and input costs. However, this primal approach is empirically demanding due to its data requirements. Therefore, as suggested by Chambers and Just (1989), we resort to dual approach, which assumes that farmers choose their land allocations in order to maximize profits π.

The following notation is used throughout the paper. $\mathbf{y}$ is a C-dimensional vector of outputs, and $\mathbf{p}$ is the corresponding price vector. $\mathbf{x}$ is a K-dimensional vector of variable inputs, and $\mathbf{w}$ is the corresponding price vector. $\mathbf{z}$ is a vector that includes the other fixed factors than land including remaining environmental and policy factors that could have effects on production decisions.[10] We include one fixed input land L that is allocated to a set of feasible crops. We assume that there is one output per each land allocation. $\mathbf{l}$ is a C-dimensional vector of allocated land, and it sums to the total land area: $\sum_{c=1}^{C} l_c = L$. $\boldsymbol{\tau}$ is a C-dimensional vector of area based subsidy payments.

We assume that producers maximize their profits:

$$\pi(\mathbf{p}, \mathbf{w}, \mathbf{z}, \mathbf{l}, \boldsymbol{\tau}) = \max \{\mathbf{p}'\mathbf{y} - \mathbf{w}'\mathbf{x} + \boldsymbol{\tau}'\mathbf{l} : \ \mathbf{y} \in Y(\mathbf{x}, \mathbf{z}, \mathbf{l})\} \tag{1}$$

Chambers and Just (1989) showed that the profit function can be presented for the optimal land allocation as:

$$\pi(\mathbf{p}, \mathbf{w}, \mathbf{z}, L, \boldsymbol{\tau}) = \max_{\mathbf{l}} \left\{ \pi^c(\mathbf{p}, \mathbf{w}, \mathbf{z}^{\mathbf{c}}, l_1, \ldots, l_c, \boldsymbol{\tau}) : \sum_{c=1}^{C} l_c = L \right\} \tag{2}$$

Fezzi and Bateman (2011) showed that by normalizing equation (2) with total land area L, we can express the profit function in per unit of land π^L terms, as shares rather than quantities:

$$\pi^L(\mathbf{p}, \mathbf{w}, \mathbf{z}, L, \boldsymbol{\tau}) = \max_{\mathbf{s}} \left\{ \sum_{c=1}^{C} \pi^L(\mathbf{p}, \mathbf{w}, \mathbf{z}, \boldsymbol{\tau}, s_1, \cdots, s_c) \ : \sum_{c=1}^{C} s_c = 1 \right\} \tag{3}$$

where $\mathbf{s}$ is the share of total land allocated to C crops. This could be expressed as a sum over crop-specific incomes:

[10] Chambers and Just (1989) distinguish between joint and nonjoint inputs. In our model only land's jointness is made explicit, whereas the same could be applied to other fixed factors as well.

$$\pi^L(\mathbf{p},\mathbf{w},\mathbf{z},L,\boldsymbol{\tau}) = \max_{\mathbf{s}} \left\{ \sum_{c=1}^{C} \pi_c^L(p_c,\mathbf{w},z_c,s_c) + \sum_{c=1}^{C} \tau_c s_c \ : \sum_{c=1}^{C} s_c = 1 \right\} \tag{4}$$

where

$$\pi_c^L(p_c,\mathbf{w},z_c,s_c) = \max_{y_c,\mathbf{x}_c} \{p_c y_c - \mathbf{w}'\mathbf{x}_c \ : y_c = f_c(\mathbf{x}_c,s_c)\} \tag{5}$$

is a crop-specific income. There are two stages. In the first, the supply function is defined to each allocation of variable inputs (equation 5). In the second, the total area is allocated optimally between crops (equation 4). We can use the envelope theorem in order to get the optimal share for each crop:

$$\frac{\partial \pi_c^L(p_c,\mathbf{w},z_c,s_c)}{\partial s_c} + \tau_c = \lambda \quad \forall c = 1,\cdots,C \tag{6}$$

where λ is the Lagrange multiplier of the total area constraint. Comparative statics of the problem are presented in appendix A.

2.2 Empirical specification

Our empirical specification employs the normalized quadratic (NQ) profit function suggested by Lau (1974). It is a flexible functional form that includes linear, squared and interaction terms for each exogenous variable. It is convenient as it accommodates negative profits and is thus widely applied in modeling agricultural production systems (e.g. Moore et al. (1994), Oude Lansink and Peerlings (1996), Guyomard et al. (1996), Moro and Sckokai (1999), Sckokai and Moro (2006), Arnade and Kelch (2007) and Fezzi and Bateman (2011)). Shumway and Lim (1993) showed that it performs better than commonly used translog functional form, which overestimates responses. We define the vector of normalized unit output and input prices as $\mathbf{r} = (\mathbf{p}/w_n, \mathbf{w}/w_n)$ where w_n is the price numeraire input n. $\mathbf{z}^* = (\mathbf{z}, L)$ are the exogenous policy and natural factors that include the total land area. The function can be written as

$$
\begin{aligned}
\bar{\pi}^L =&\alpha_0+ \\
&\sum_{c=1}^{C+K-1} \alpha_c r_c + \frac{1}{2} \sum_{c=1}^{C+K-1} \sum_{d=1}^{C+K-1} \alpha_{cd} r_c r_d + \\
&\sum_{c=1}^{C-1} \beta_c s_c + \frac{1}{2} \sum_{c=1}^{C-1} \sum_{d=1}^{C-1} \beta_{cd} s_c s_d + \\
&\sum_{c=1}^{K+1} \gamma_c z_c^* + \frac{1}{2} \sum_{c=1}^{K+1} \sum_{d=1}^{K+1} \gamma_{cd} z_c^* z_d^* + \\
&\sum_{c=1}^{C-1} \delta_c \tau_c + \frac{1}{2} \sum_{c=1}^{C-1} \sum_{d=1}^{C-1} \delta_{cd} \tau_c \tau_d + \\
&\sum_{c=1}^{C+K-1} \sum_{d=1}^{C-1} \zeta_{cd} r_c s_d + \sum_{c=1}^{C+K-1} \sum_{d=1}^{K+1} \vartheta_{cd} r_c z_d^* + \\
&\sum_{c=1}^{C+K-1} \sum_{d=1}^{C-1} \iota_{cd} r_c \tau_d^* + \sum_{c=1}^{C-1} \sum_{d=1}^{K+1} \phi_{cd} s_c z_d^* + \\
&\sum_{c=1}^{C-1} \sum_{d=1}^{C-1} \varphi_{cd} s_c \tau_d + \sum_{c=1}^{K+1} \sum_{d=1}^{C-1} \kappa_{cd} z_c^* \tau_d
\end{aligned} \tag{7}
$$

for each crop pairs c and d. $\bar{\pi}^L = \frac{\pi^L}{w_n}$ is the normalized profit per unit of land. Index $C - 1$ denotes the number of equations in the system that omits one equation due to its redundancy.[11] The symmetry conditions require that $\alpha_{cd} = \alpha_{dc}$, $\beta_{cd} = \beta_{dc}$, $\gamma_{cd} = \gamma_{dc}$, and $\delta_{cd} = \delta_{dc}$.

By differentiating for each share s_c we get the optimal land shares per crop:

$$
\begin{aligned}
\frac{\partial \pi}{\partial s_1} =&\beta_1 + \sum_{d=1}^{C+K-1} \delta_{1d} r_d + \sum_{d=1}^{C-1} \beta_{1d} s_d + \sum_{d=1}^{K+1} \phi_{1d} z_d^* + \sum_{d=1}^{C-1} \varphi_{1d} \tau_d = \\
&\beta_c + \sum_{d=1}^{C+K-1} \delta_{cd} r_c + \sum_{d=1}^{C-1} \beta_{cd} s_d + \sum_{d=1}^{K+1} \phi_{cd} z_d^* + \sum_{d=1}^{C-1} \varphi_{cd} \tau_d = \frac{\partial \pi}{\partial s_c}, \\
&\text{for } c = 2, \cdots, C-1 \\
&\text{with } \sum_{c=1}^{C} s_c = 1
\end{aligned} \tag{8}
$$

The corresponding system of reduced form equations is

[11] The residual equation can be computed from the included equations.

$$s_c = \theta_c + \sum_{d=1}^{C+K-1} \theta_{cd} r_d + \sum_{d=1}^{K+1} \mu_{cd} z_d^* + \sum_{d=1}^{C} \nu_{cd} \tau_c \tag{9}$$

for $c = 1, \cdots, C$. The following parameter restrictions apply:

$$\sum_{c=1}^{h} \theta_c = 1 \tag{10}$$

$$\sum_{c=1}^{h} \theta_{cd} = 0, d = 1, \cdots, C + K - 1 \tag{11}$$

$$\sum_{c=1}^{h} \mu_{cd} = 0, d = 1, \cdots, K + 1 \tag{12}$$

$$\sum_{c=1}^{h} \nu_{cd} = 0, d = 1, \cdots, C \tag{13}$$

Due to lack of data on some farm-level variables such as input use, we resort to abstract from estimating the parameters related to production technologies and instead follow the example of Fezzi and Bateman (2011). Variation in production technologies is merely controlled by farm- and regional-level variables. The estimated model nevertheless allows us to calculate elasticities and semi-elasticities of subsidy payments on crop production decisions (defined as allocation of land). Quantities of interest are between direct crop-specific subsidy payments and the share of cultivated area. The elasticity is defined as:

$$\eta_c = \frac{\partial s_c}{\partial \tau_c} \frac{\tau_c}{s_c} \tag{14}$$

It measures a *percentage* (i.e. relative) change in shares with respect to a percentage change in a subsidy rate. The corresponding semi-elasticity[12] is

$$\text{APE}_c = \frac{\partial s_c}{\partial \tau_c} \tau_c \tag{15}$$

It measures a *percentage point* (i.e. absolute) change in a crop share with respect to a *percentage* (i.e. marginal) change in a subsidy rate. Both quantities therefore measure responsiveness of land use decisions to changes in subsidy rates, but their interpretation differs. As the semi-elasticity treats changes along a share distribution

[12]Semi-elasticities are also called either average partial effects (APEs) or marginal effects depending on literature.

equally, it is less sensitive to prevailing shares. Furthermore, in contrast to elasticities, semi-elasticities converge to zero when a subsidy rate becomes very large. We report both the elasticities and semi-elasticities.

These elasticity estimates can also be interpreted as approximations of supply price elasticities in absence of price risk given expected yields per hectare.[13] Some evidence exists that price risk is not a major factor in farm decision making. Koundouri et al. (2009) found that price risk is relatively small part of total income risk for Finnish farmers: 18% for wheat and 2% for barley while yield risk clearly dominates total production risk. Thus the estimated elasticities are probably reasonable approximations of price elasticities during stable, low price risk periods.[14]

3 Data and methods

3.1 Data

We use farm- and field-level data, which contain much richer detail than aggregated data and avoids many problems identified in aggregate data analysis. Our data includes field level observations of crop allocations of all the Finnish farms between 1997 and 2002. It includes variables of general use of each field (namely agriculture or other), cultivated crop on a field that is in agricultural use, and ownership status of a field (own or rented). Accompanying data includes farm level characteristics such as subsidy payments by category, indicator of organic production, owned forest land, and farmer's age.

The data has several tiers of geographic indicators. Each field has geographic indicators of its center-point, and it is located in a municipality. Apart from few exceptions, municipalities lie within one subsidy region.[15] Subsidy payments vary by subsidy regions. However, each farm can cultivate fields that are located in several municipalities and therefore on several subsidy regions as well. Thus farms that have fields in several subsidy regions, receive subsidy income based on differing conditions. Figure 1 depicts the Finnish subsidy regions in the relevant period of the policy reform.

Empirical analysis exploits variation in subsidy rates before and after the Agenda

[13]Nerlove (1956) already claimed that such acreage elasticity is a lower limit of the actual supply elasticity. His solution was to model price expectations explicitly. Our approach exploits the minimal uncertainty in subsidy payments, which circumvents modeling the price expectations and resorting to associated assumptions about the expectation coefficient.

[14]Periods of high price risk–such as the recent Russia sanctions–do happen, and responses in those circumstances are likely to deviate from our estimates.

[15]The exceptions are islands that have no land connection, which always belong to region B.

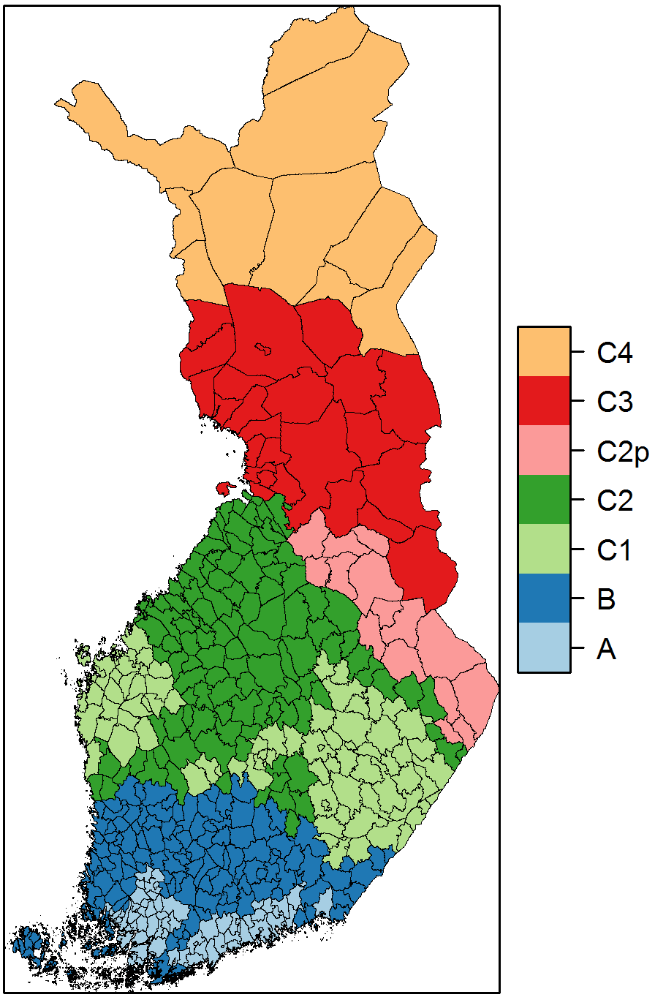

Figure 1: The agricultural subsidy regions in Finland (1995-2014).

2000 reform between regions A and B. We chose three years before and after the reform, 1997-2002, in our empirical application. We included all the observation from regions A and B, with an exception of Åland island, which belongs to region B and is geographically and climatically distinct and subject to a separate agri-environmental scheme. Table 1 displays mean crop cultivation shares in subsidy regions' cereal and oilseed farms three years before (1997-1999) and after (2000-2002) the reform. Table 2 does the same for the crop share trends. The crops are wheat, feed barley, oats, malting barley, rye, oilseeds, other crops and setaside. The table reveals that wheat is the most common cultivated crop in region A, but in region B it is fairly uncommon. In region B the main feed crops oats and feed barley are more common than in region A. Natural conditions favorable for cultivation of bread cereals (wheat and rye) do not extend much beyond the southernmost areas. In further north the bread cereal yields become riskier and cultivation is less common. Furthermore, the quality requirements for bread cereals are stricter and risk for lower quality harvests also increases towards north.

Table 1: Mean crop shares before and after the Agenda 2000, regions A and B cereal and oilseed farms.

Subsidy region	Reform	Wheat	Feed barley	Malting barley	Oats	Rye	Oilseeds	Setaside	Other
A	pre	0.32	0.17	0.13	0.13	0.03	0.04	0.10	0.09
A	post	0.31	0.10	0.15	0.16	0.03	0.04	0.11	0.08
B	pre	0.03	0.28	0.07	0.31	0.02	0.05	0.14	0.09
B	post	0.05	0.18	0.11	0.37	0.03	0.03	0.14	0.09

Table 2: Trends of crop shares before and after the Agenda 2000, regions A and B cereal and oilseed farms.

Subsidy region	Reform	Wheat	Feed barley	Malting barley	Oats	Rye	Oilseeds	Setaside	Other
A	pre	0.03	-0.02	0.01	-0.00	-0.00	-0.01	-0.01	-0.00
B	pre	-0.00	-0.00	0.00	0.01	0.00	-0.00	-0.01	-0.00
A	post	-0.01	-0.02	0.00	0.01	-0.00	0.00	0.01	-0.00
B	post	0.01	-0.03	0.01	0.02	-0.00	-0.00	0.00	-0.00

Figures 2, 4 and 4 show the development of the crop-specific area payments in regions A and B in euros per hectare and normalized to years 1999 and 2000, respectively. The payments are calculated as sums of CAP, LFA, environmental subsidy and Finnish national payments in crop production. In general the payments were lower in region A before the reform. The exception is wheat, which received a higher subsidy in region A for reasons we have already refered to. Differences in other crops are already minor before the reform, and after the reform they virtually disappear. Oilseeds is an exception, which that continued receiving sligthly higher compensation in region B after the reform.

Tables 3 and 4 summarize immediate and mean subsidy rate changes after the reform, respectively. The majority of change happens immediately after the reform, although disparity is slightly higher in the whole period for all the crops except malting barley.

Decision on whether a farm plants a certain crop could have path dependency as habits and preferences affect the decision process. Figure 5 depicts the frequency of crops' appearance in farms crop mixes. The data includes all cereal and oilseed farms in regions A and B that were active in 1995-2014. The figure reveals that in region A around quarter of the farms did not plant wheat in any of the years whereas in region B that share was 40%. In contrast, more than 30% of region A farms cultivated wheat

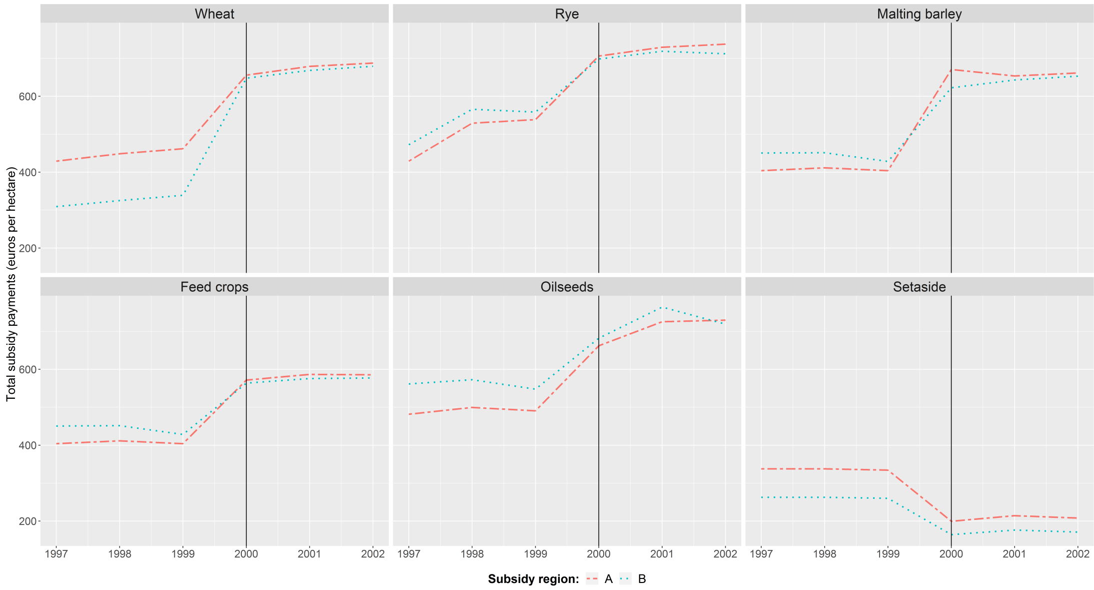

Figure 2: The agricultural subsidy payments per hectare in A and B region before and after the Agenda 2000 reform (euros per hectare).

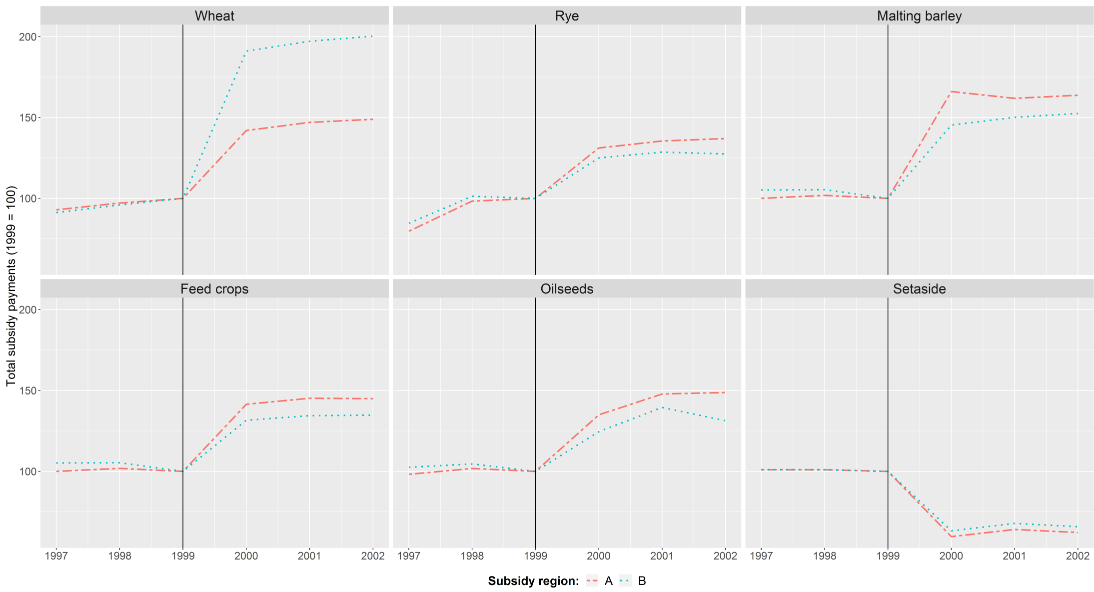

Figure 3: The agricultural subsidy payments per hectare in A and B region before and after the Agenda 2000 reform (year 1999 = 100).

each year, whereas in region B only few percents of farms did so. The plot shows that a significant share of farms have not cultivated wheat, rye, malting barley or oilseeds at all during the 20 year period. On the other hand, feed barley and oats are relatively common for any farm to cultivate. Especially in region B oats is very common in the

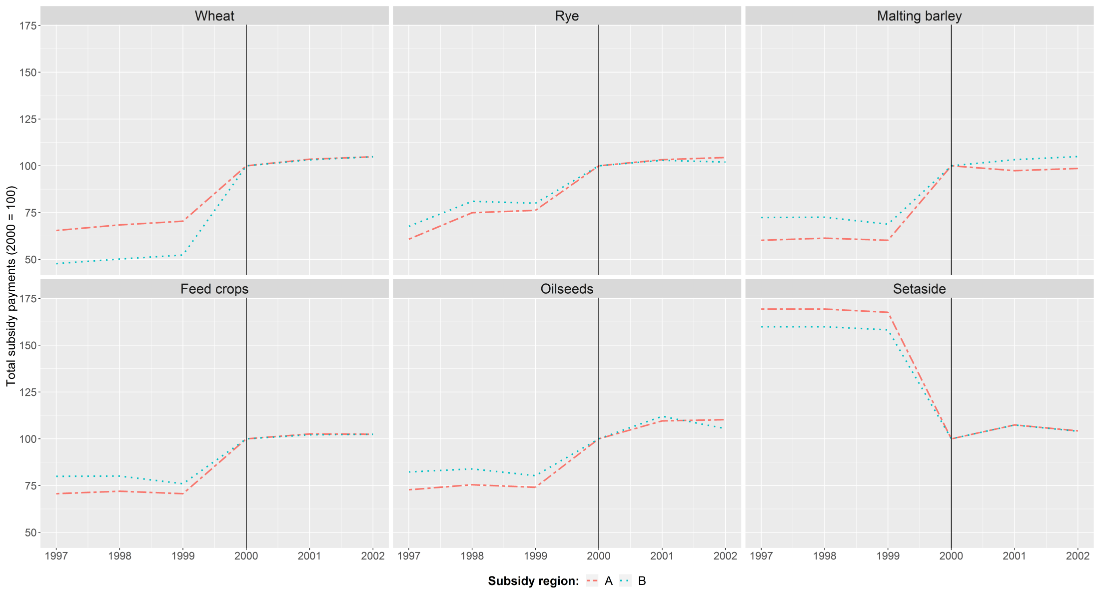

Figure 4: The agricultural subsidy payments per hectare in A and B region before and after the Agenda 2000 reform (year 2000 = 100).

Table 3: Immediate crop-specific subsidy rate changes (1999-2000).

Crop	Region A	Region B	deviation
Feed crops	41.50	31.58	9.92
Malting barley	66.07	45.32	20.74
Oilseeds	34.93	24.55	10.38
Rye	31.13	24.97	6.17
Setaside	-40.34	-36.80	-3.54
Wheat	41.98	91.04	-49.06

crop mix. It is also very common to have some other non-specified crop included in the crop mix. Setaside is also very common to have constantly even though it was not mandatory in each year of the time series.[16]

3.2 Empirical setting

We exploit exogenous policy change in the Finnish Agenda 2000 implementation in order to estimate the effect of subsidy payments on changes in crop mix. The setting allows us to control endogeneity with the standard differences-in-differences (DiD) model with crop shares as dependent variables. Explanatory variables include three binary variables that characterize the DiD setting: 1) a dummy variable for change in

[16]Setaside was mandatory for the period 1997-2002, which we use in our estimations. It was suspended in 2009, which is included in the time series of figure 5.

Table 4: Mean crop-specific subsidy rate changes (whole period).

Crop	Region A	Region B	deviation
Feed crops	42.98	29.04	13.95
Malting barley	62.87	44.23	18.64
Oilseeds	43.83	28.77	15.07
Rye	45.17	33.33	11.84
Setaside	-38.43	-34.85	-3.58
Wheat	50.96	104.93	-53.96

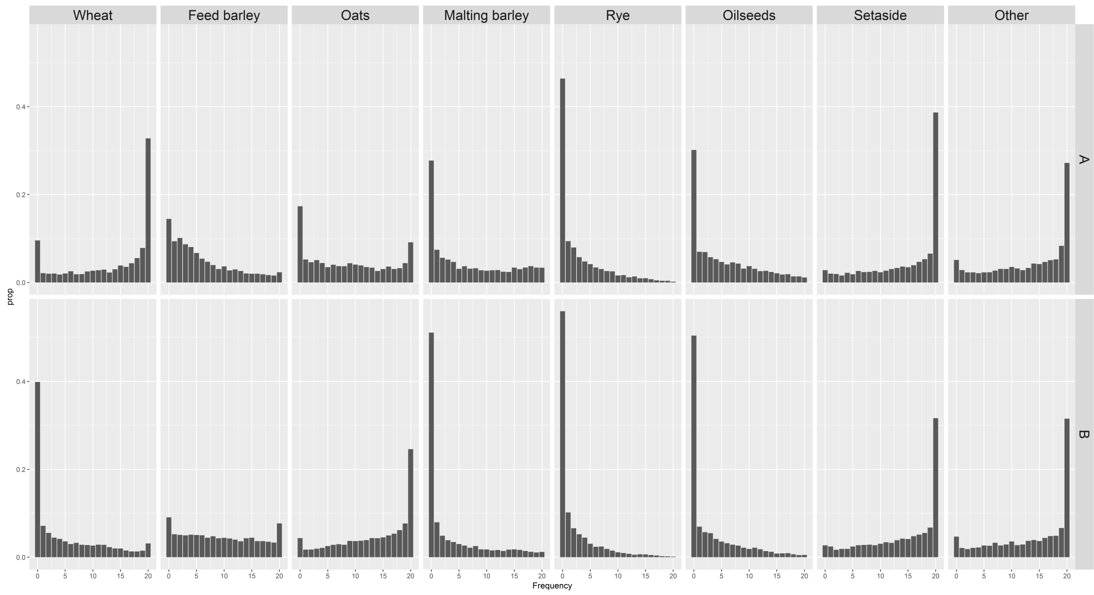

Figure 5: Frequency of a crop in farms' planting decisions in regions A and B.

time (zero for before the reform and one for after), 2) a dummy variable for treated versus non-treated region (zero for a region with a set of new crop-specific subsidy rates and one for its neighboring region with a different set), and 3) the product of these two, which is the DiD variable. Changes in the LFA payments in the Agenda 2000 effectively created a DiD setting between regions A and B. Region A is considered the treated region as its subsidy rate for wheat was "corrected" in the reform.[17] Furthermore, as changes in crop-specific area payments are the only elements in the policy reform with regional variation, they are reflected in the DiD coefficients. If the subsidies affect farmers' crop mix decision, the DiD coefficients should be statistically significant.[18]

[17]The designation of the treated region is somewhat arbitrary in our case as the subsidy rates changed to some extent for all the crops in both regions.

[18]The first application of DiD estimation in economics was by Card and Krueger (1994) on minimum wages and employment in the US. Towe and Tra (2012) applied a DiD setting in order to estimate the US ethanol mandate effects on farmland prices. Kazukauskas et al. (2013) used a DiD setting in order to find the causal effect between decoupled subsidies and disinvestments and exits. They used farm-level

We apply four different estimators: ordinary least squares (OLS) without and with farm level fixed effects, and fractional response Probit with either pooled or general correlated random effects (CRE). Our empirical models for the first two are:

$$E(s_{it}|\mathbf{x}_{it}, \theta) = \alpha + \mu_t + \gamma A_s + \psi d_p + \delta D_{st} + \sigma \mathbf{x}_{it} + \epsilon_{it} \tag{16}$$

$$E(s_{it}|\mathbf{x}_{it}\theta_i) = \alpha_i + \mu_t + \gamma A_s + \psi d_p + \delta D_{st} + \sigma \mathbf{x_{it}} + \epsilon_{it} \tag{17}$$

where s_{it} is the share of a crop in a farm i's crop mix of planted hectares in year t, A_s is the dummy variable for a farm being in the treated region (region A), d_p is the dummy variable for time periods before and after the treatment and $D_{st} = A_s * d_p$ is the DiD variable. $\mathbf{x}_{it}$ is a matrix of covariates. $\theta = (\alpha, \mu, \gamma, \psi, \delta, \sigma, \epsilon)$ is a vector of all the estimated parameters: α (constant term in OLS), α_i (farm level fixed effects), μ (individual year t effects), γ (treatment group s effect), ψ (treatment period p effect), δ (DiD effect) and σ (the vector of covariate coefficients). The estimates of δ are the causal effects of interest. ϵ is the error term for which $E(\epsilon|t) = 0$.

Our empirical model for the fractional response Probit applies two CRE estimators–pooled and general–in order to control for unobserved heterogeneity. Pooled CRE can be expressed as:

$$E(y_{it}|\mathbf{x}_{it}, \theta) = \Phi(\alpha + \mu_t + \gamma A_s + \psi d_p + \delta D_{st} + \sigma(\mathbf{x}_{it} - \bar{\mathbf{x}}_i) + \bar{\sigma}\bar{\mathbf{x}}_i + \epsilon_{it}) \tag{18}$$

where $\Phi()$ is the standard normal cumulative density function. The estimator controls unobserved heterogeneity by taking farm-level averages over continuous covariates $\bar{\mathbf{x}}_i = \frac{1}{T}\sum_{t=1}^{T} \mathbf{x}_{it}$.[19]

The general CRE includes also farm-level random effects, and its error term can be expressed as:

$$\epsilon_{it} = v_i + \eta_{it} \tag{19}$$

where v_i are the farm-level random effects.

The parameters of interest in the fractional response model are APEs rather than the estimated coefficients. The APEs are semi-elasticities and they can be obtained by

data on all the EU countries and exploited the member states' choice for adopting Fischler reform either in 2005 or 2006.

[19] The formulation of demeaning the covariates differs form the original suggestion by Mundlak. Bell and Jones (2015) showed that the estimated coefficients are only comparable to non-corrected models if $\mathbf{x}_{it} - \bar{\mathbf{x}}_i$ is used instead of $\mathbf{x}_{it}$

differencing. For continuous variables we get:

$$\mathrm{APE}_{\mathbf{x}_t} = \frac{\partial E(y_t|\mathbf{x}_t, c)}{\partial x_{tj}} = \sigma_j \phi(\mathbf{x_t}\boldsymbol{\sigma} + c) \tag{20}$$

and for discrete variables:

$$\mathrm{APE}_{\mathbf{x}_t} = \Phi(\mathbf{x}_t^{(1)}\boldsymbol{\sigma} + c) - \Phi(\mathbf{x}_t^{(0)}\boldsymbol{\sigma} + c) \tag{21}$$

where we drop time indexes and include a constant c.

We included total agricultural area, farmer's age, share of rental land, total area forest land, applied environmental subsidies by hectare, organic production dummy, and setaside requirement dummy as farm level covariates. The covariates hypothetically address some of the fundamental sources of farm level heterogeneity. Farmers' age could reflect varying tendencies for choosing various crops. For instance the elderly farmers might be less likely to adopt new crops. Larger farms are probably better able to diversify their crop mix. Farms that rent majority of their fiels could have shorter sight on maintaining field growth conditions and thus less regard to crop rotations. Farms that own large areas of forest, could be less than fulltime farmers with tendency for less risky and time consuming crops in their mix. Environmental subsidies correlate with less productive technologies, and organic production certainly has techonological constraints such as choosing crops that do not depend on chemical inputs. As discussed earlier, only the largest farms were required to have setaside land, which is controlled by a dummy variable. Local time dependent effects are controlled with year-region dummies at LAU1[20] regional classification level that is one level higher in aggregation than the municipalities (LAU2). LAU1 regions are typically centered around a regional urban center, which is usually also the center of regional crop markets. Thus the dummies effectively control regional market variation including prices and local weather conditions. Tables 5 and 6 summarize the descriptive statistics of the variables included in estimated models for regions A and B, respectively.

In order to derive the APEs and elasticity values for the subsidy payments we calculated a farm specific subsidy rate, which includes all area based subsidy payments of each farm that could be associated to a certain crop. Four main categories of payments exist. First, the CAP payments for crop farms vary between subsidy regions and three crop categories: cereals, oilseeds and setaside. In addition, after the Agenda 2000 reform, cereals and oilseeds received a drying-bonus, which varied between subsidy regions. In general, the CAP payments are based on historical yields, and

[20]LAU is a geographical classification by Eurostat and it stands for Local Administrative Unit.

Table 5: Descriptive statistics of region A farms included in model (1997-2002).

Statistic	Mean	Median	St. Dev.
Area (ha)	36.733	26.620	33.893
Share of rented land	0.130	0	0.260
Age	49.302	50	11.530
Envir. subs. uptake	0.945	1	0.227
Organic	0.049	0	0.216
Setaside req.	0.378	0	0.485
Wheat share	0.317	0.3	0.304
Feed barley share	0.130	0.000	0.241
Malting barley share	0.137	0.000	0.231
Oats share	0.152	0.000	0.248
Rye share	0.029	0	0.082
Oilseeds share	0.042	0.000	0.115
Setaside share	0.107	0.092	0.122
Other crops share	0.087	0.003	0.176

Table 6: Descriptive statistics of region B farms included in model (1997-2002).

Statistic	Mean	Median	St. Dev.
Area (ha)	27.299	19.300	26.124
Share of rented land	0.117	0	0.239
Age	49.383	50	11.393
Envir. subs. uptake	0.890	1	0.313
Organic	0.047	0	0.212
Setaside req.	0.209	0	0.407
Wheat share	0.046	0.000	0.141
Feed barley share	0.218	0	0.292
Malting barley share	0.095	0	0.222
Oats share	0.342	0.3	0.311
Rye share	0.024	0	0.079
Oilseeds share	0.037	0	0.115
Setaside share	0.143	0.105	0.155
Other crops share	0.095	0.004	0.181

thus region A received higher payments than region B. Second, the LFA payments were paid to cereal and oilseed crops with regional variation favoring region B. As mentioned earlier, region A and wheat were not eligible for LFA payment before the Agenda 2000 reform. Third, environmental payments were paid at a common rate for cereals and oilseeds, and at a lower rate for setaside until the Agenda 2000, which removed the payment from setaside. Environmental subsidies were also set at a higher level in region A as a compensation to region's exclusion from the LFA payment. In the reform environmental subsidies were harmonized between regions. Finally, some national payments are paid in addition to the EU payments. National payments include more categories for crops. Our analysis includes wheat, rye, malting barley, feed crops and oilseeds.[21] Summing these four categories together, we get a crop-specific subsidy rate. The take-up rate of the environmental payments is 90% of observations in our sample. We thus calculated different subsidy rates for farms depending on whether they applied for environmental subsidies.[22]

The data is slightly unbalanced as some farms leave production during the study period (see table 7 for unbalance by region). The OLS models are not affected by unbalance, but the fractional response models assume balanced panels by default. If the unbalance is not properly controlled in fractional response models, that can lead to inconsistent estimates. We apply the robust method suggested by Wooldridge (2010) and implemented by Bluhm et al. (2018) in robustness checks only.[23] The checks do not display significant deviation from omitting the unbalancedness control. In addition, the general CRE is not currently feasible with unbalancedness control.

Table 7: Panel data unbalance by region (percentages of included years for an individual farm).

	A	B
1	2.3%	3.2%
2	6.8%	8.2%
3	7.4%	9.9%
4	7.4%	9.1%
5	76.1%	69.7%

A common problem with DiD regression is that error terms could be correlated with each other spatially in clusters. By clustering the error terms on a higher spatial level (in this case municipalities), we can avoid a possible serial correlation problem.

[21]In addition the following crops are eligible for national area payments: grass (animal farms only), sugar beet, starch potatoes, vegetables grown in the open, and apples.

[22]Detailed subsidy rate calculations are available upon request.

[23]See table 12 for the results

3.3 Estimation framework

In order to assess the land allocation problem empirically, a few issues related to model specification need to be considered. First, dependent variables are restricted to values between one and zero. This inherent non-linearity makes a generalized linear model (GLM) a natural choice. Second, the decisions are likely to be correlated as the chosen crop mix could be subject to technological constraints such as crop rotations and other farm specific preferences. Thus due to correlated error terms, joint estimation of a system of equations should be preferred. On the other hand, a careful analysis of causal mechanisms restrict the available methods. The literature includes a multitude of approaches to this problem, which we aim to summarize in this section. The main categories are the limited dependent variable systems of equations 3.3.1, their Bayesian and maximum entropy alternatives 3.3.2, beta and Dirichlet regressions 3.3.3 and fractional response models 3.3.4. Unobserved heterogeneity needs to be controlled in order to reliably identify causality. An independent section 3.3.5 is devoted to various strategies in dealing with this problem in various frameworks. Section 3.3.6 gives justification for the model choice in our problem.

3.3.1 Limited dependent variable systems of equations

Realization that dependent variables are shares, has deeply affected empirical work on demand systems. The majority of the literature interprets this as a case for estimating a system of equations, which has limited dependent variables. More specifically, dependent variables are limited between values zero and one, and they should add up to unity. The first econometric models that could incorporate these limitations were censoring models, which assume that some of the observations are censored at some values, e.g. negative values appearing as zeros. However, suitability of the censored dependent variable framework is not universally accepted for models that have shares as dependent variables. For instance, Maddala (1991) argues that zero observations are not censored in any meaningful sense but represent an inappropriate use of censored regression modeling. This section summarizes empirical work related to both interpretations starting with more prevalent case of censored dependent variable models and proceeds to more explicit solutions, which model the corner solutions in separate stages.

Estimation of limited dependent variables as censored quantities was first proposed by Tobin (1958), and further developed by Amemiya (1973) for single equation case, and extended to multiple equation systems by Amemiya (1974). The Amemiya-Tobin approach is based on deterministic budget shares, which relate to observed shares by normal disturbances. Truncated multivariate normal specification ensures that shares lie between zero and one. Studies that apply Amemiya-Tobin approach include Wales and Woodland (1983), Yen, B.-H. Lin, and Smallwood (2003), Yen and B.-H. Lin (2008), Dong et al. (2004) and Fezzi and Bateman (2011).

An alternative approach that is based on deriving the estimated model from Kuhn-Tucker conditions was proposed by Wales and Woodland (1983). The approach assumes maximization of a resulting random profit function. In contrast to Amemiya-Tobin, shadow (or virtual) prices of the censored observations become explicitly defined. Lee and Pitt (1986, 1987) further developed the method by starting from its dual, which conveniently allows flexible demand specifications suggested by Diewert and Wales (1987). However, additional difficulties appear. First, shadow (or virtual) prices of commodities that are not chosen are naturally unobserved. Therefore the likelihood function is of a mixed discrete-continuous form and thus its estimation requires evaluation of multivariate probability integrals, which is computationally heavy and easily leads to the curse of dimensionality. Second, internal consistency of the model cannot be guaranteed.[24] Amemiya-Tobin approach does circumvent the problem, but at a cost of ignoring the shadow prices. Because of these difficulties, empirical applications of Kuhn-Tucker approach have remained rare (e.g. Phaneuf et al. (2000)).

Whereas Amemiya-Tobin and Lee-Pitt approaches assume that censored observations are a result of decisions based on shadow prices, more explicit attempts to deal with censoring exist. Heien and Wesseils (1990) suggested a two-step approach, which assigns separate processes for censoring (e.g. a decision to cultivate a crop) and scale when not censored (e.g. how large share to assign to that crop). Shonkwiler and Yen (1999) applied and further developed the method. Yen (2005) generalized Heckman's sample-selection model to multivariate case, which nests bivariate sample-selection and two-part models. Other studies that apply two-step approach include Lacroix and Thomas (2011), who apply two-step method suggested by Wooldridge (1995).

Yen, B.-H. Lin, and Smallwood (2003) compare simulated maximum likelihood (SML), quasi-maximum likelihood (QML) and two-step estimator approaches to estimating Amemiya-Tobin system. They found that SML and QML produce very similar results despite QML being computationally more feasible. On the other hand, their choice of two-step procedure turns out to be inefficient and its coefficient estimates deviate significantly from both ML results. On the other hand both Yen (2005) and Lacroix and Thomas (2011) compared their multivariate two-step methods to Tobit approach. Their methods produce more consistent coefficient estimates. One strength

[24] This is the statistical coherency problem by Gourieroux, Laffont, et al. (1980)

of the Lacroix-Thomas approach is that it easily controls unobserved heterogeneity with fixed effects.

Yen and B.-H. Lin (2008) avoid the curse of dimensionality problem related to repeated evaluations of bivariate normal probability integrals in a QML estimator by applying a copula approach. The approach also conveniently incorporates non-Gaussian assumptions. Their results also indicate that the assumption of multivariate normal error terms might not be warranted.

A recent work by Koutchadé et al. (2018a) propose an endogenous regime switching model that is micro-economically consistent with respect to corner solutions and does not violate the adding-up condition. In contrast to censored system modeling, the approach explicitly models the corner solution decisions. The empirical application of the model employs the stochastic approximate expectation maximization (SAEM) algorithm.

3.3.2 Bayesian and maximum entropy alternatives

The adding-up condition cannot be met in majority of applications if the system of C shares is estimated because that would lead to singular covariance matrix. A common solution is to drop one of the equations and estimate the remaining system of $C - 1$ equations. However, in case of censored equations that leads to invariance problem: the coefficient estimates are not invariant to the dropped equation. Wales and Woodland (1983) showed that invariancy can be achieved by a mapping mechanism that relates observed shares with latent ones. More specifically, they suggest that

$$y_{ih} = \begin{cases} \frac{y_{ih}^*}{\sum_h^H y_{ih}^*} & \text{if} \quad y_{ih}^* > 0 \\ 0 & \text{if} \quad y_{ih}^* \leq 0 \end{cases} \tag{22}$$

where quantities with and without asterisks denote latent and observed dependent variables, respectively. Indexes i and h denote observations and equations, respectively. Kasteridis et al. (2011) showed with simulated data that ignoring the adding-up constraint produces biased estimates. Dong et al. (2004) solve the invariancy problem in Amemiya-Tobin framework with SML estimation. The most general way to ensure adding-up is the Bayesian framework, which has been applied in at least following studies: Millimet and Tchernis (2008), Tiffin and Arnoult (2010), Kasteridis et al. (2011) and Bilgic and Yen (2014). All of them apply Gibbs sampler in order to recover the posterior, and data augmentation in order to ensure adding-up properties. According to Millimet and Tchernis (2008) their proposed method is fully consistent, avoids high-dimensional integration, and imposes only minimal set of restrictions. The multinomial logit model used by Carpentier and Letort (2014) is also consistent with the adding-up restriction.

Finally, maximum entropy (ME) methods can be applied, e.g. Arndt (1999) and Heckelei and Wolff (2003). Although the approach does not omit shadow prices, its general properties are not well understood. Koutchadé et al. (2018b) apply Monte Carlo expectation maximization (MCEM) algorithm to crop mix decision problem. They are able to take into account heterogeneous responses of farmers with a random parameter model. They find that the farmers' responses are heterogeneous enough to warrant explicit modeling.

3.3.3 Beta and Dirichlet regression

Kieschnick and McCullough (2003) and Ferrari and Cribari-Neto (2004) offer an alternative interpretation of estimating functions that have shares observed on the open interval (0,1) as dependent variables. They explicitly model the dependent variable as a random quantity that has a beta distribution, which is conveniently defined between zero and one. As the beta distribution does not include the extreme values one and zero, either a transformation of dependent variable (e.g. a log-ratio transformation) or a two-step procedure would be required for estimating censored equations. The Dirichlet distribution is a multivariate generalization of the beta distribution and can be applied in multivariate analysis of compositional data (a vector of random quantities restricted to the unit simplex).

While applying either beta or Dirichlet regression circumvents some of the shortcomings in traditional econometric work (e.g. multivariate normal distribution of error terms need not to be assumed, and there is no need to omit an equation in order to prevent singularity Murteira and Ramalho (2016)), it introduces some of its own. The first is that neither distribution includes extreme values. Two possible solutions exist. First, dependent variable could be transformed in cases that they are few and not important. Commonly used transformations include additive, centered and isometric log-ratios. However, resulting coefficient estimates are not easy to interpret after a transformation and the approach could not be recommended when the frequency of extreme values is high. Second, a two-stage approach like zero-or-one inflated beta regression (Ospina and Ferrari, 2012) could be applied. Some applications of Dirichlet regression to compositional economic data exist, e.g. Leininger et al. (2013), Feng, Zhu, P.-S. Lin, et al. (2014), Feng, Zhu, and Steen-Adams (2015) and Feng, Zhu, P.-S. Lin, et al. (2017), which all apply some form of two-stage Dirichlet regression. Yet the interpretation of parameter values remains a problem. The second shortcoming of the Dirichlet distribution is that it imposes a negative correlation for each pair of dependent variables. In case that crop mix decisions could be influenced by crop rotation considerations, that feature is clearly not desirable.

3.3.4 Fractional response models

Another approach are the fractional response models developed by Papke and Wooldridge (1996) for cross-sectional, and Papke and Wooldridge (2008) for panel data). The model is of form $E(y_i|\mathbf{x_i}) = F(\mathbf{x_i'}\boldsymbol{\beta})$, where $y_i \in [0,1]$. It uses a Bernoulli log-likelihood function:

$$l_i(\boldsymbol{\beta}) \equiv y_i \log[F(\mathbf{x_i'}\boldsymbol{\beta})] + (1 - y_i)\log[1 - F(\mathbf{x_i'}\boldsymbol{\beta})] \tag{23}$$

where $\boldsymbol{\beta}$ is a parameter and $0 < F(\cdot) < 1$ is a link function, e.g. logit or Probit.[25] The maximization problem could be solved either with NLS or QML, of which the latter is favored by the authors due to its efficiency. Additionally, QML does not require information on the true distribution, only that the conditional mean is correctly specified (Gourieroux, Monfort, et al., 1984). As it is based on well developed GLM techniques, it can readily incorporate relevant features of microeconometric analysis like clustered error terms and spatial autocorrelation.

A multivariate generalization of the approach exists, but it is still not fully developed to exploit panel data (e.g. Gourieroux, Monfort, et al. (1984), Mullahy and S. A. Robert (2010), Carpentier and Letort (2014), Molowny-Horas et al. (2015), and Mullahy (2015)). However, Mu et al. (2013), and Cho and McCarl (2017) applied multivariate logit models to predict the US land use and crop mix shifts due to climate change, respectively.

3.3.5 Unobserved heterogeneity

The causal interpretation could only be established with a reasonable certainty if unobserved heterogeneity is adequately controlled. Carpentier and Letort (2012) also showed that controlling unobserved heterogeneity is important in modeling farm level input use, i.e. multicrop production choice. There are several ways to achieve this. The commonly used fixed effects are unfortunately not applicable with the majority of non-linear models. However, some reasonable alternatives exist. Random effects model is available for many non-linear settings, but its assumption of *iid* error terms could

[25] Although both logit and Probit models are commonly associated with binary response models, they are not restricted to them and could straightforwardly incorporate more general cases like fractional responses.

be too restrictive for many applications.[26] Carpentier and Letort (2012) suggested an empirically tractable solution that uses a control function. Papke and Wooldridge (2008) applied correlated random effects (CRE), or "Mundlak-Chamberlain device",[27] in order to control unobserved heterogeneity in a fractional response model. The authors suggest that the CRE estimator should be favored in short time series fractional response panel models since the alternative, fixed effects fractional logit model typically produces inconsistent fixed effects estimates due to incidental parameter problem. Dieleman and Templin (2014) showed with a simulation that the CRE estimator is as efficient and unbiased way to control unobserved heterogeneity as fixed effects, while random effects is clearly biased. In finite samples the CRE outperforms both traditional random and fixed effects. The authors conclude that the estimator is underutilized in current literature.

3.3.6 Justification for model choice

Evidently a multitude of estimators exist for fractional dependent variable problems. However, different estimators have their trade-offs and a perfect estimator cannot be conceived. It seems that from the three desirable features (explicit modeling of fractional dependent variable, estimation of a whole system of equations, and controlling unobserved heterogeneity satisfactorily with either fixed effects or CRE procedure) only two can be applied simultaneously. Insistence for fixed effects would further constrain the options to single equation linear models. We chose to apply the model proposed by Papke and Wooldridge (2008), because it has the following desirable features: 1) the estimator explicitly incorporates the inherent non-linearity of the model and includes both extreme values; and 2) it does not require omitting variables nor setting some of the variables as a base level. Kieschnick and McCullough (2003) reviewed various strategies to model proportional dependent variables and they ended up recommending either beta regression or QML fractional response models. The former should be preferred unless sample size is large enough for the latter. Our sample size clearly justifies the use of the QML alternative. We also do corresponding OLS and OLS with farm level fixed effects models for comparison and as a robustness check.

There are also two alternatives for a link function in a binary dependent variable models. Papke and Wooldridge (2008) use the Probit link because it allows for including

[26] See Meyerhoefer et al. (2005) who include random effects in order to control unobserved heterogeneity and estimate a system in GMM framework.

[27] Other names for this strategy found in the literature are the between estimator or the within-between estimator. As an example of crop share models, Lacroix and Thomas (2011) control unobserved heterogeneity with CRE procedure, which they call *Mundlak fixed effects estimation*. The strategy could be considered as a compromise between random and fixed effects strategies.

endogenous explanatory variables and deriving average partial effects (APEs) that are straightforward to interpret. The logit in contrast does not yield consistent APEs when dependent variable is non-binary. We follow the authors in this decision and also apply Probit in our models.

Unobserved heterogeneity can be controlled with CRE, which avoids incidental parameters problem in a short panel like ours. However, CRE is by default applicable to balanced panels only, which limits its usability. Nevertheless, some strategies that correct the attritional heteroscedasticity exists, e.g. with robust method suggested by Wooldridge (2010) and implemented by Bluhm et al. (2018). Unfortunately, the method accommodates only the pooled CRE. We applied the robust method as a robustness check and did not find large differences.

For elasticity estimates, we also implement multivariate logit model, which takes into account correlations between individual crops. In that case we also control for unobserved heterogeneity with CRE. Although logit has its disadvantages, it is feasible for the multivariate case whereas Probit is not. We present both univariate fractional Probit and multivariate logit results and find no significant differences.

4 Results

4.1 Crop-specific area payments

We report estimation results for seven crops and setaside land. Tables 8 and 9 display the results of the cross-sectional and fixed effects OLS models, respectively. We can see that fixed effects correction slightly changes some of the DiD coefficient values. Coefficients in the fixed effect models are statistically significant for each crop except oats and malting barley. Wheat experienced the most visible policy change and its DiD coefficient (-0.036 - -0.041) is also the largest. The interpretation is that the Agenda 2000 reform caused a 3-4% decline in wheat cultivation in region A *in comparison to region B*. The negative sign is expected - subsidy rate for wheat changed 42% in region A and 91% in region B (see table 3). Thus wheat started to receive more area-based payments in both regions, while the relative increase was much higher in region B. In other words, region A lost some of its comparative advantage in wheat cultivation *in comparison to region B*. The other crops experience smaller policy changes, and their cultivation shares were affected by the reform as well. The signs are mostly as expected: a relative increase (decrease) in a subsidy rate causes a relative increase (decrease) in cultivation shares. The only significant coefficient with unintuitive sign is the OLS model coefficient for oats. Nevertheless, it is not possible to draw conclusions on substitution patterns between the crops, although the category other crops,[28] has significant, positive coefficient indicating increased cultivation in region A because of reform. The reform also affected setaside allocation negatively, which follows from the reduction in setaside premium, which was steeper in region A in comparison to region B. It is also somewhat surprising that malting barley has no significant change due to policy change although the change in subsidy rates between regions is the second highest after wheat. This could be explained by the fact that malting barley is a contract crop and thus its cultivation cannot adjust as flexibly as with non-contract crops. Processing industry has only one firm, which has only one processing location. Thus it can only offer a certain amount of contracts and likely has some monopoly power. Therefore the processing industry's capacity could be limiting farms' cultivation decisions. Oilseed production is also based on contracts, but with more widely distributed processing industry.

Table 8: OLS estimates

	Wheat b/se	Feed barley b/se	Oats b/se	Malting barley b/se	Rye b/se	Oilseeds b/se	Setaside b/se	Other b/se
Post-reform period	0.252***	-0.199***	-0.039	-0.051	-0.038***	-0.038**	0.046	0.068*
	(0.07)	(0.02)	(0.02)	(0.03)	(0.01)	(0.01)	(0.09)	(0.03)
Region A	0.223***	-0.067***	-0.065***	-0.035	-0.011***	-0.020**	0.023**	-0.048***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.00)	(0.01)	(0.01)	(0.01)
Post-reform period * Region A	-0.036***	0.020	-0.030**	0.000	0.013***	0.016***	-0.031***	0.047***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)
Controls	✓	✓	✓	✓	✓	✓	✓	✓
Unobserved heterogeneity control	None	None	None	None	None	None	None	None
Clustering	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality
N	79471	79471	79471	79471	79471	79471	79471	79471
R^2	0.36	0.09	0.18	0.12	0.09	0.04	0.15	0.14
AIC	-29843	14716	20768	-20504	-183357	-121214	-94178	-59347
BIC	-28729	15830	21882	-19390	-182243	-120091	-93064	-58234

The years included in the sample are 1997-2002, of which the years starting in 2000 are the post-reform period. The sample includes the farms that have cultivated fields in these years on either subsidy region A or subsidy region B or both. The included controls are year and LAU1 region dummies, total area, rental share, forest area, farmer's age and age squared, environmental subsidy rate, and dummies for organic production and setaside requirement. Organic dummies and setaside requirement were dropped from setaside due to non-convergence. Other crops include among others potatoes, sugar beet, peas, broad beans and flax seeds. t statistics are in parentheses and the significance levels are presented with asterisks: * p<0.05, ** p<0.01, *** p<0.001.

Tables 10 and 11 display the marginal effects of the fractional response model with pooled and general CRE estimators, respectively. The DiD coefficients are similar in comparison to the linear models. They are significant for wheat, rye, oilseeds and setaside. The DiD coefficients for wheat (-0.032 for pooled and -0.06 for general CRE) are significant and comparable to the linear models' coefficients. The pooled CRE specification indicates the weakest causal effect, while the general CRE indicates the strongest.

[28] This category aggregates over all the crops that do not receive crop-specific payments including potatoes, sugarbeet, peas, broad beans and flaxseed.

Table 9: OLS with fixed effects estimates

	Wheat b/se	Feed barley b/se	Oats b/se	Malting barley b/se	Rye b/se	Oilseeds b/se	Setaside b/se	Other b/se
Post-reform period	-0.010**	0.252***	0.003	-0.005	0.002	-0.306***	0.064***	-0.001
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Region A	0.009	-0.042	0.010	0.053	-0.013**	-0.007	0.040*	-0.050*
	(0.03)	(0.04)	(0.05)	(0.03)	(0.00)	(0.01)	(0.02)	(0.02)
Post-reform period * Region A	-0.041***	0.031**	-0.012	-0.013	0.011***	0.012**	-0.025***	0.037***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.00)
Controls	✓	✓	✓	✓	✓	✓	✓	✓
Unobserved heterogeneity control	FE	FE	FE	FE	FE	FE	FE	FE
Clustering	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality
N	79471	79471	79471	79471	79471	79471	79471	79471
R^2	0.03	0.06	0.03	0.04	0.02	0.01	0.08	0.06
AIC	-137069	-62147	-75149	-91907	-245020	-167881	-204986	-187723
BIC	-136075	-61154	-74147	-90904	-244027	-166888	-204002	-186729

The years included in the sample are 1997-2002, of which the years starting in 2000 are the post-reform period. The sample includes the farms that have cultivated fields in these years on either subsidy region A or subsidy region B or both. The included controls are year and LAU1 region dummies, total area, rental share, forest area, farmer's age. The included controls are year and LAU1 region dummies, total area, rental share, forest area, farmer's age and age squared, environmental subsidy rate, and dummies for organic production and setaside requirement. Organic dummies and setaside requirement were dropped from setaside due to non-convergence. Other crops include among others potatoes, sugar beet, peas, broad beans and flax seeds. t statistics are in parentheses and the significance levels are presented with asterisks: * p<0.05, ** p<0.01, *** p<0.001.

As we saw, the DiD coefficients are fairly similar in each model. However, the time and treated coefficients differ significantly between the models. For instance, the OLS and fractional response models indicate statistically significant changes for both variables with wheat, while the fixed effects OLS finds almost none. Thus the fixed effects correction allocates majority of the variation to the reform, and very little to time trend and regional differences. On the other hand, both OLS and fractional response models find also variation that favors region A over B, and post-reform over pre-reform.

Figure 6 depicts the DiD coefficient estimates for each crop and model. In general, the differences by model are modest. The Probit with general CRE stands out with more extreme coefficient estimates for wheat and rye, and wider confidence intervals in general.

Tables 12 and 13 display how various control measures compare to each other.[29] Table 12 displays the results for wheat shares with varying control selections with the fractional Probit model. The table shows that controlling yearly and regional variation affects the DiD coefficients the most while the effects of other controls is negligible. The DiD coefficient has a larger mean value when year-region dummies are included. Table 13 displays estimation results with various heterogeneity controls for wheat shares. The first two columns display the OLS models without and with CRE correction. The third column is the fixed effects panel model, while the final two columns have the fractional response model margins without and with CRE correction. The DiD coefficients are

[29]We include here only wheat, while equivalent tables for the other crops are available upon request.

Table 10: Fractional Probit marginal effects (pooled CRE)

	Wheat b/se	Feed barley b/se	Oats b/se	Malting barley b/se	Rye b/se	Oilseeds b/se	Setaside b/se	Other b/se
Post-reform period	0.189***	-0.243***	-0.052*	-0.715***	-0.212***	-0.033*	0.069	0.066***
	(0.04)	(0.03)	(0.03)	(0.09)	(0.01)	(0.02)	(0.08)	(0.02)
Region A	0.156***	-0.065***	-0.091***	-0.037	-0.010***	-0.017**	-0.003	-0.032***
	(0.01)	(0.02)	(0.02)	(0.02)	(0.00)	(0.01)	(0.01)	(0.01)
Post-reform period * Region A	-0.032***	0.007	-0.005	0.001	0.011***	0.011***	-0.015**	0.025***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)
Controls	✓	✓	✓	✓	✓	✓	✓	✓
Unobserved heterogeneity control	CRE (pooled)	CRE (pooled)	CRE (pooled)	CRE (pooled)	CRE (pooled)	CRE (pooled)	CRE (pooled)	CRE (pooled)
Clustering	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality
N	79471	79471	79471	79471	79471	79471	79471	79471
pseudo-R^2	.37	.09	.19	.12	.09	.04	.09	.15
AIC	41877	61100	69657	42469	15085	21409	46097	37798
BIC	43167	62363	70920	43239	15827	22691	47267	39070
$\sqrt{MSE}$	.199	.265	.274	.212	.076	.113	.138	.165

The years included in the sample are 1997-2002, of which the years starting in 2000 are the post-reform period. The sample includes the farms that have cultivated fields in these years on either subsidy region A or subsidy region B or both. The included controls are year and LAU1 region dummies, total area, rental share, forest area, farmer's age and age squared, environmental subsidy rate, and dummies for organic production and setaside requirement. Organic dummies and setaside requirement were dropped from setaside due to non-convergence. Other crops include among others potatoes, sugar beet, peas, broad beans and flax seeds. t statistics are in parentheses and the significance levels are presented with asterisks: * p<0.05, ** p<0.01, *** p<0.001.

Table 11: Fractional Probit marginal effects (general CRE)

	Wheat b/se	Feed barley b/se	Oats b/se	Malting barley b/se	Rye b/se	Oilseeds b/se	Setaside b/se	Other b/se
Post-reform period	0.410***	-0.395***	0.007	-0.168*	-0.127	-0.074	0.072	0.138
	(0.05)	(0.05)	(0.05)	(0.08)	(0.07)	(0.05)	(0.13)	(0.16)
Region A	0.255***	-0.090**	-0.127***	-0.010	-0.049***	-0.042**	0.017	-0.107
	(0.02)	(0.03)	(0.03)	(0.03)	(0.01)	(0.01)	(0.02)	(0.13)
Post-reform period * Region A	-0.060***	0.009	-0.009	-0.017	0.041***	0.025*	-0.031**	0.033**
	(0.01)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Controls	✓	✓	✓	✓	✓	✓	✓	✓
Unobserved heterogeneity control	CRE (general)	CRE (general)	CRE (general)	CRE (general)	CRE (general)	CRE (general)	CRE (general)	CRE (general)
Clustering	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality
N	79300	79460	79460	78678	79379	79176	79460	79460
pseudo-R^2	.3	.06	.11	.11	.06	.04	.01	.05
AIC	48367	82639	71481	55599	47513	47712	56626	70959
BIC	49852	84161	73004	56990	49017	49169	58111	72481
$\sqrt{MSE}$	2.86	.969	1.107	2.358	2.436	2.358	3.709	1.163

The years included in the sample are 1997-2002, of which the years starting in 2000 are the post-reform period. The sample includes the farms that have cultivated fields in these years on either subsidy region A or subsidy region B or both. The included controls are year and LAU1 region dummies, total area, rental share, forest area, farmer's age and age squared, environmental subsidy rate, and dummies for organic production and setaside requirement. Organic dummies and setaside requirement were dropped from setaside due to non-convergence. Other crops include among others potatoes, sugar beet, peas, broad beans and flax seeds. t statistics are in parentheses and the significance levels are presented with asterisks: * p<0.05, ** p<0.01, *** p<0.001.

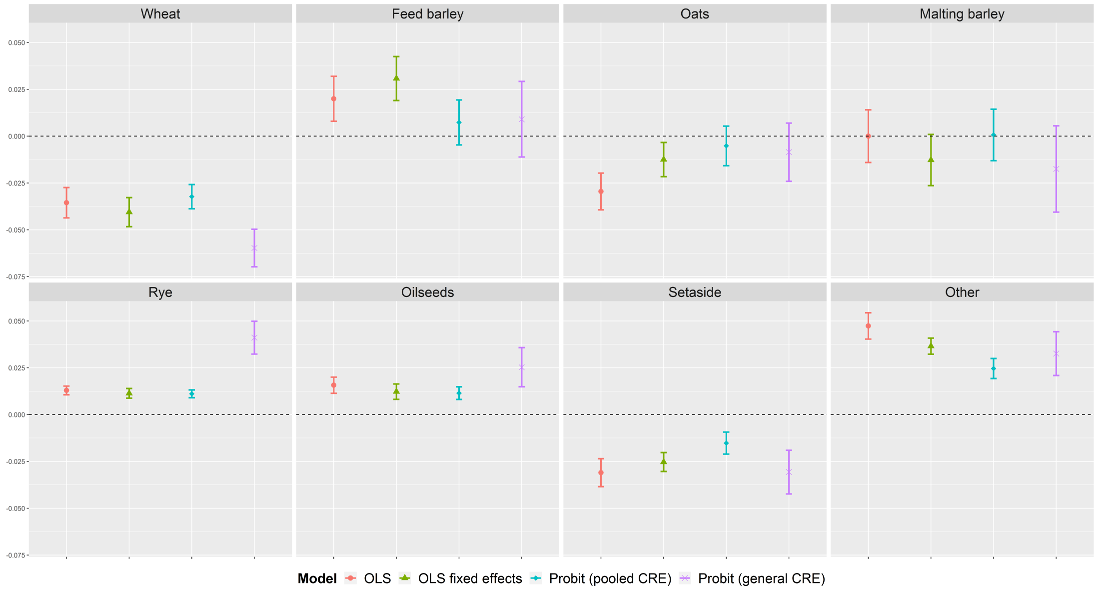

Figure 6: Differences-in-differences coefficient estimates by model and crop (with 0.95 confidence intervals).

larger when unobserved heterogeneity is controlled. It is largest with the OLS fixed effects model. CRE correction alters the OLS results slightly, but has no effect with the fractional response model. Clustering at municipality level does not affect coefficient significance.

4.2 Elasticities

We calculated both elasticities and semi-elasticities by fractional response models with general CRE specification. An advantage of the Probit specification over linear models is that we can include more information as we do not need to omit zero observations nor resort to additional aggregation of crops that would result in fewer zero observations and less information. Linear models could also be first-differenced, but that would also omit all the information on crop levels. In addition, Bluhm et al. (2018) found with Monte Carlo experiments that linear model elasticity estimates are biased. The model differs from the one we used for the causal analysis. As the elasticities are essentially prediction quantities, we omit the DiD specific dummy variables. In addition, the year-region dummies are omitted due to convergence issues. Instead we include year dummies. The APEs are calculated as a derivative of equation (18) with respect to the subsidy rate:

Table 12: Fractional Probit marginal effects for wheat with various control variables

	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se
Post-reform period	0.022***	0.018***	0.018***	0.015**	0.164***	0.162***	0.162***	0.335***	0.023***	0.018***	0.018***
	(0.00)	(0.00)	(0.00)	(0.01)	(0.04)	(0.04)	(0.04)	(0.06)	(0.00)	(0.00)	(0.00)
Region A	0.245***	0.242***	0.242***	0.418***	0.167***	0.165***	0.165***	0.279***	0.245***	0.243***	0.243***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
Post-reform period * Region A	-0.024***	-0.020***	-0.020***	-0.044***	-0.035***	-0.031***	-0.031***	-0.057***	-0.028***	-0.024***	-0.024***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Year-region dummies	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes
CRE	No	No	Pooled	General	No	No	Pooled	General	No	No	Pooled
Unbalance corrected	No	No	No	No	No	No	No	No	Yes	Yes	Yes
Clustering	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality	Municipality
N	79471	79471	79471	79471	79471	79471	79471	79300	79471	79471	79471
AIC	45564.26	45560.74	45560.74	53820.5	42639.6	42641	42641	51700.51	54775.59	54772.8	54772.8
BIC	45601.39	45672.14	45672.14	53941.18	43781.43	43857.09	43857.09	53111.22	54886.99	54958.47	54958.47

The years included in the sample are 1997-2002, of which the years starting in 2000 are the post-reform period. The sample includes the farms that have cultivated fields in these years on either subsidy region A or subsidy region B or both. The included controls are year and LAU1 region dummies, total area, rental share, forest area, farmer's age and age squared, environmental subsidy rate, and dummies for organic production and setaside requirement. t are statistics in parentheses and the significance levels are presented with asterisks: * p<0.05, ** p<0.01, *** p<0.001.

Table 13: Comparison of heterogeneity controls for wheat

	OLS	OLS	OLS with CRE (pooled)	OLS with CRE (pooled)	OLS with CRE	OLS with CRE	Fixed effects	Fixed effects	Fractional Probit	Fractional Probit	Fractional Probit with CRE (pooled)	Fractional Probit with CRE (pooled)	Fractional Probit with CRE	Fractional Probit with CRE
	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se
Post-reform period	0.219***	0.219**	0.245***	0.245***	0.239***	0.239**	0.000	-0.010**	0.162***	0.162***	0.189***	0.189***	0.410***	0.410***
	(0.04)	(0.07)	(0.04)	(0.07)	(0.04)	(0.07)	(0.03)	(0.00)	(0.05)	(0.04)	(0.05)	(0.04)	(0.06)	(0.05)
Region A	0.229***	0.229***	0.221***	0.221***	0.210***	0.210***	0.009	0.009	0.165***	0.165***	0.156***	0.156***	0.255***	0.255***
	(0.00)	(0.02)	(0.00)	(0.02)	(0.00)	(0.02)	(0.02)	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)
Post-reform period * Region A	-0.031***	-0.031***	-0.034***	-0.034***	-0.040***	-0.040***	-0.041***	-0.041***	-0.031***	-0.031***	-0.032***	-0.032***	-0.060***	-0.060***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Year-region dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Unbalance corrected	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Unobserved heterogeneity control	No	No	CRE (pooled)	CRE (pooled)	CRE (general)	CRE (general)	FE	FE	No	No	CRE (pooled)	CRE (pooled)	CRE (general)	CRE (general)
Clustering	No	Municipality	No	Municipality	No	Municipality	No	Municipality	No	Municipality	No	Municipality	No	Municipality
N	79471	79471	79471	79471	79471	79471	79471	79471	79471	79471	79471	79471	79300	79300
AIC	-27592.15	-27680.15	-29787.02	-29877.02			-137012.64	-137066.64	42711	42643	41947.14	41877.14	48367.02	48367.02
BIC	-26051.15	-26547.61	-28171.75	-28679.49			-135759.42	-136064.06	44252	43868.38	43562.41	43167.5	49851.98	49851.98

The years included in the sample are 1997-2002, of which the years starting in 2000 are the post-reform period. The sample includes the farms that have cultivated fields in these years on either subsidy region A or subsidy region B or both. The included controls are year and LAU1 region dummies, total area, rental share, forest area, farmer's age and age squared, environmental subsidy rate, and dummies for organic production and setaside requirement. t statistics are in parentheses and the significance levels are presented with asterisks: * p<0.05, ** p<0.01, *** p<0.001.

$$\mathrm{APE}_c^{s\tau} = \frac{\partial \hat{E}[s_c|\tau_c]}{\partial \tau_c} = \hat{\sigma} \times \phi(\hat{\alpha} + \hat{\sigma} \ln \tau_c)\tau_c \tag{24}$$

where ϕ is the standard normal density function. The corresponding elasticities are:

$$\hat{\epsilon}_c^{s\tau} = \frac{\partial \hat{E}[s_c|\tau_c]}{\partial \tau_c} \frac{\tau_c}{\hat{E}[s_c|\tau_c]} = \hat{\sigma} \times I(\hat{\alpha} + \hat{\sigma} \ln \tau_c) \tag{25}$$

where $I = \frac{\phi()}{1-\Phi()}$ is the inverse Mills ratio. From equation (25) we can derive elasticity values for the whole range of crop shares.

Tables 14 and 15 summarize the elasticities and the semi-elasticities of crop shares to subsidy payments, respectively. The columns present the crop shares and rows the crop-specific area payment rates (e.g. 'wheatSR' is the subsidy rate for wheat). The main interest is with crops' own subsidy elasticities. All own subsidy elasticities are positive with an exception of oilseeds that has an economically unintuitive negative elasticity estimate, which is not statistically significant. The positive estimates are all significant with an exception of malting barley. Wheat is quite elastic to subsidy payments with statistically significant value 2.3 for the elasticity and 0.5 for the semi-elasticity. Interpretation for the former is that one *percent* change in subsidy rate causes 2.3 *percent* change in wheat share. The latter means that one *percent* change in subsidy rate causes 0.5 *percentage point* increase in cultivated wheat area. The results indicate that the cultivation of all the crops in our analysis is very elastic to coupled area-based payments.

The cross-subsidy elasticities could be indicative of crop rotational dependencies between the crops - a positive cross-subsidy elasticity implying that crop's cultivation increases when another crop's subsidy increases. Wheat cultivation is also positively affected with subsidies to malting barley and rye. The feed crops have similar dependence with oilseeds. Oilseeds cultivation is more elastic to setaside payments than to its own subsidy, which could indicate a rotational dependence.

Tables 16 and 17 present the elasticity and semi-elasticity estimates of the multivariate fractional logit system, respectively. The estimates are somewhat lower than with single equation Probit models' values, e.g. an elasticity value 1.7 for wheat (2.3 in single equation case). The differences are small in general, but they indicate that further development of multivariate approach could be warranted.[30]

[30]Heterogeneity control in the multivariate models corresponds to the pooled CRE model and they are thus not fully comparable with elasticity values presented in tables 14 and 15

Table 14: Crop share subsidy elasticities (fractional Probit model)

	Wheat	Feed barley	Oats	Malting barley	Rye	Oilseeds	Setaside	Other
wheatSR	2.333***	-0.831***	-0.0136	2.848***	0.298	0.838	0.464***	-0.518
	(0.250)	(0.208)	(0.104)	(0.403)	(0.459)	(0.501)	(0.112)	(0.396)
feedSR	-43.22***	13.03***	12.38***	-10.95***	0.0558	-7.536*	2.729***	2.630*
	(2.608)	(1.944)	(0.950)	(3.317)	(3.031)	(3.035)	(0.818)	(1.216)
mBarleySR	12.27***	-4.037***	-3.015***	2.642**	-0.258	-0.612	-0.692***	-0.712*
	(0.628)	(0.428)	(0.224)	(0.844)	(1.016)	(0.846)	(0.192)	(0.283)
ryeSR	58.82***	-16.72***	-16.80***	15.65***	3.089	14.62***	-3.597**	-3.568*
	(3.885)	(2.748)	(1.427)	(4.584)	(3.603)	(4.401)	(1.180)	(1.779)
oilseedsSR	-22.03***	5.843***	5.538***	-5.944***	-0.922	-1.351	1.434***	1.034
	(1.349)	(0.785)	(0.490)	(1.658)	(1.228)	(1.452)	(0.398)	(0.644)
setasideSR	-0.584***	0.618***	-0.0258	-1.463***	-0.433	-0.779	0.127*	0.0166
	(0.161)	(0.115)	(0.0713)	(0.285)	(0.326)	(0.435)	(0.0572)	(0.0804)
Observations	79471	79471	79471	79471	79471	79471	79471	79471

The years included in the sample are 1997-2002, of which the years starting in 2000 are the post-reform period. The sample includes the farms that have cultivated fields in these years on either subsidy region A or subsidy region B or both. The included controls are year and LAU1 region dummies, total area, rental share, forest area, farmer's age and age squared, environmental subsidy rate, and dummies for organic production and setaside requirement. Organic dummies and setaside requirement were dropped from setaside due to non-convergence. Other crops include among others potatoes, sugar beet, peas, broad beans and flax seeds. t are statistics in parentheses and the significance levels are presented with asterisks: * p<0.05, ** p<0.01, *** p<0.001.

Table 15: Crop share subsidy semi-elasticities (fractional Probit model)

	Wheat	Feed barley	Oats	Malting barley	Rye	Oilseeds	Setaside	Other
wheatSR	0.502***	-0.300***	-0.00766	0.542***	0.0362	0.0940	0.255***	-0.311
	(0.0501)	(0.0735)	(0.0588)	(0.0765)	(0.0562)	(0.0559)	(0.0613)	(0.225)
feedSR	-8.886***	4.869***	7.048***	-1.990***	0.00681	-0.858*	1.502**	1.572*
	(0.407)	(0.688)	(0.462)	(0.599)	(0.370)	(0.342)	(0.466)	(0.738)
mBarleySR	2.539***	-1.493***	-1.716***	0.485**	-0.0314	-0.0692	-0.381***	-0.426*
	(0.0911)	(0.145)	(0.115)	(0.154)	(0.124)	(0.0957)	(0.109)	(0.168)
ryeSR	12.13***	-6.209***	-9.564***	2.852***	0.377	1.653***	-1.981**	-2.134*
	(0.635)	(0.974)	(0.698)	(0.831)	(0.440)	(0.490)	(0.670)	(1.078)
oilseedsSR	-4.466***	2.190***	3.170***	-1.071***	-0.112	-0.153	0.790***	0.618
	(0.209)	(0.278)	(0.246)	(0.295)	(0.148)	(0.164)	(0.227)	(0.394)
setasideSR	-0.128***	0.242***	-0.0140	-0.259***	-0.0537	-0.0936	0.0691*	0.00980
	(0.0349)	(0.0446)	(0.0388)	(0.0476)	(0.0406)	(0.0520)	(0.0310)	(0.0473)
Observations	79471	79471	79471	79471	79471	79471	79471	79471

The years included in the sample are 1997-2002, of which the years starting in 2000 are the post-reform period. The sample includes the farms that have cultivated fields in these years on either subsidy region A or subsidy region B or both. The included controls are year and LAU1 region dummies, total area, rental share, forest area, farmer's age and age squared, environmental subsidy rate, and dummies for organic production and setaside requirement. Organic dummies and setaside requirement were dropped from setaside due to non-convergence. Other crops include among others potatoes, sugar beet, peas, broad beans and flax seeds. t are statistics in parentheses and the significance levels are presented with asterisks: * p<0.05, ** p<0.01, *** p<0.001.

Table 16: Crop share elasticities (multinomial logit system)

	Wheat b/se	Feed barley b/se	Oats b/se	Malting barley b/se	Rye b/se	Oilseeds b/se	Setaside b/se	Other crops b/se
wheatSR	1.680***	-1.959***	-1.353***	1.822***	0.257	1.240	4.931***	-4.935***
	(0.49)	(0.31)	(0.24)	(0.55)	(0.67)	(0.72)	(0.50)	(0.49)
feedSR	-48.558***	14.461***	17.068***	-7.873*	-5.602	-11.219**	3.052**	8.054***
	(3.17)	(2.20)	(1.51)	(3.57)	(3.20)	(3.55)	(1.17)	(2.28)
mBarleySR	14.447***	-4.556***	-4.400***	0.877	1.233	0.350	0.319	-2.744***
	(0.80)	(0.56)	(0.40)	(0.85)	(0.93)	(1.05)	(0.35)	(0.51)
ryeSR	64.855***	-20.762***	-23.943***	12.300**	10.431*	20.530***	-2.125	-13.344***
	(4.79)	(3.26)	(2.12)	(4.77)	(4.42)	(5.23)	(1.75)	(3.37)
oilseedsSR	-24.471***	7.408***	7.892***	-3.706*	-2.756	-3.238	1.361*	3.798***
	(1.67)	(0.97)	(0.78)	(1.63)	(1.57)	(1.75)	(0.57)	(1.00)
setasideSR	-0.424	1.007***	-0.040	-1.343**	-0.644	-1.435*	-0.052	1.254***
	(0.35)	(0.17)	(0.14)	(0.42)	(0.57)	(0.62)	(0.16)	(0.28)
Observations	79471	79471	79471	79471	79471	79471	79471	79471

The years included in the sample are 1997-2002, of which the years starting in 2000 are the post-reform period. The sample includes the farms that have cultivated fields in these years on either subsidy region A or subsidy region B or both. The included controls are year and LAU1 region dummies, total area, rental share, forest area, farmer's age and age squared, environmental subsidy rate, and dummies for organic production and setaside requirement. Organic dummies and setaside requirement were dropped from setaside due to non-convergence. Other crops include among others potatoes, sugar beet, peas, broad beans and flax seeds. t statistics are in parentheses and the significance levels are presented with asterisks: * p<0.05, ** p<0.01, *** p<0.001.

Table 17: Crop share semi-elasticities (multinomial logit system)

	Wheat b/se	Feed barley b/se	Oats b/se	Malting barley b/se	Rye b/se	Oilseeds b/se	Setaside b/se	Other crops b/se
wheatSR	0.186**	-0.309***	-0.305***	0.187**	0.007	0.038	0.615***	-0.418***
	(0.06)	(0.05)	(0.06)	(0.06)	(0.02)	(0.03)	(0.06)	(0.04)
feedSR	-5.676***	2.144***	3.683***	-0.522	-0.129	-0.342**	0.255	0.588**
	(0.44)	(0.35)	(0.33)	(0.35)	(0.08)	(0.13)	(0.14)	(0.18)
mBarleySR	1.722***	-0.679***	-0.930***	0.002	0.027	-0.010	0.076	-0.207***
	(0.10)	(0.09)	(0.08)	(0.08)	(0.02)	(0.04)	(0.04)	(0.04)
ryeSR	7.589***	-3.078***	-5.200***	0.882	0.249*	0.657***	-0.097	-1.003***
	(0.67)	(0.52)	(0.46)	(0.48)	(0.11)	(0.19)	(0.21)	(0.27)
oilseedsSR	-2.815***	1.115***	1.699***	-0.240	-0.063	-0.081	0.109	0.277***
	(0.22)	(0.15)	(0.17)	(0.16)	(0.04)	(0.06)	(0.07)	(0.08)
setasideSR	-0.043	0.180***	-0.030	-0.135**	-0.017	-0.054*	-0.007	0.106***
	(0.05)	(0.03)	(0.03)	(0.04)	(0.01)	(0.02)	(0.02)	(0.02)
Observations	79471	79471	79471	79471	79471	79471	79471	79471

The years included in the sample are 1997-2002, of which the years starting in 2000 are the post-reform period. The sample includes the farms that have cultivated fields in these years on either subsidy region A or subsidy region B or both. The included controls are year and LAU1 region dummies, total area, rental share, forest area, farmer's age and age squared, environmental subsidy rate, and dummies for organic production and setaside requirement. Organic dummies and setaside requirement were dropped from setaside due to non-convergence. Other crops include among others potatoes, sugar beet, peas, broad beans and flax seeds. t statistics are in parentheses and the significance levels are presented with asterisks: * p<0.05, ** p<0.01, *** p<0.001.

5 Discussion

Our analysis has shown that direct subsidy payments and farm crop mix choices correlate largely in line with economic theory. More importantly, we could reliably show that causality is from payments to decisions. In other words, we can confidently state that farms' crop allocation were affected by changes in coupled payments. Our analysis is based on differential treatment of crop-specific area payments between subsidy regions A and B in Finland. The differential treatment of the wheat area payments was the most visible one in the reform and wheat share adjusts largely in line with the economic theory. Also the other crops, which were not subject to as visible changes in their subsidy rates, did adjust nevertheless. Rye and oilseeds shares compensated the decrease of wheat cultivation in region A.

Elasticity estimates of coupled subsidies are significant for most of the crops and have expected signs. In addition, the elasticity estimates indicate quite elastic response. Thus we can conclude that coupled subsidies differentiated by crop, even when paid as area based payments, directly affect the production decisions. Elasticity estimates largely follow the economic logic. The only exception is oilseeds that has a negative elasticity estimate. We have no conclusive explanation for this finding, although oilseeds popularity in crop rotations could play some role.

6 Conclusion

In this study we have examined how coupled subsidy payments affect farmers' production decisions. We could exploit a quasi-experimental setting that emerged between Finnish subsidy regions in the Agenda 2000 reform as crop-specific direct payments were harmonized between regions. More specifically we examined changes in crop share decisions with traditional linear models and fractional response Probit model with differences-in-differences identification strategy for controlling endogeneity. Our strategy for controlling unobserved heterogeneity used both traditional fixed effects in the linear model, and correlated random effects in the fractional response model.

We found that crop-specific subsidy payments have effect on production decisions at least for wheat, rye, oilseeds and setaside. The effects that are significant are well in line with economic theory as farmers were found to adjust their cultivation decisions in parallel to its price change. The linear and fractional response models yielded similar interpretations, but the latter has certain advantages in calculating the elasticities and semi-elasticities.

Our models have fractions as dependent variables, but they do not address the distributional assumptions explicitly. As a futher elaboration of our study, a zero-and-one inflated beta regression could be applied for more flexible distributional considerations.

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Appendix A: Comparative statics

We start examining the comparative statics of the crop shares by totally differentiating equation (6) and solving for $\mathrm{d}s_c$. By differentiating equation (6), we get:

$$\pi^c_{s_c s_c}\mathrm{d}s_c + \pi^c_{s_c p_c}\mathrm{d}p_c + \pi^c_{s_c \mathbf{w}}\mathrm{d}\mathbf{w} + \pi^c_{s_c z_c}\mathrm{d}z_c + \mathrm{d}\tau_c = \mathrm{d}\lambda \tag{A.1}$$

where

$$\pi^c_{xy} = \frac{\partial \pi^2_c}{\partial x \partial y}. \tag{A.2}$$

By summing equation (A.1) over all C crops and substituting in the share constraint $\sum_{c=1}^{C} \mathrm{d}s_c = 0$ we get the normalized expression:

$$\sum_{c=1}^{C}[\frac{1}{\pi^c_{s_c s_c}}(\mathrm{d}\lambda - \pi^c_{s_c p_c}\mathrm{d}p_c - \pi^c_{s_c \mathbf{w}}\mathrm{d}\mathbf{w} - \pi^c_{s_c z_c}\mathrm{d}z_c - \mathrm{d}\tau_c)] = 0 \tag{A.3}$$

We can now solve the shadow price of land:

$$\mathrm{d}\lambda = \sum_{c=1}^{C}[(\pi^c_{s_c p_c}\mathrm{d}p_c + \pi^c_{s_c \mathbf{w}}\mathrm{d}\mathbf{w} + \pi^c_{s_c z_c}\mathrm{d}z_c + \mathrm{d}\tau_c)] \tag{A.4}$$

By substituting that into equation (A.1) we get the optimal land allocation:

$$\begin{aligned}
\mathrm{d}s_c = \frac{1}{\pi^c_{s_c s_c}}[&\sum_{d=1}^{C}\pi^d_{s_d p_d}\mathrm{d}p_d - \pi^c_{s_c p_c}\mathrm{d}p_c \\
&+ \sum_{d=1}^{C}\pi^d_{s_d \mathbf{w}}\mathrm{d}\mathbf{w} - \pi^c_{s_c \mathbf{w}}\mathrm{d}\mathbf{w} \\
&+ \sum_{d=1}^{C}\pi^d_{s_d z_d}\mathrm{d}z_d - \pi^c_{s_c z_c}\mathrm{d}z_c \\
&+ \sum_{d=1}^{C}\mathrm{d}\tau_d - \mathrm{d}\tau_c]
\end{aligned} \tag{A.5}$$

The following regularity conditions for the functional form apply: homogeneity of degree one and convexity in prices, monotonicity, and symmetry. Additionally, in order to ensure adding-up of the land shares, the following adding-up conditions need to apply:

$$\sum_{c=1}^{C} l_c = L \Leftrightarrow \sum_{c=1}^{C} \frac{\partial l_c}{\partial p_{c'}} = \sum_{c=1}^{C} \frac{\partial l_c}{\partial \tau_{c'}} = \sum_{c=1}^{C} \frac{\partial l_c}{\partial w_k} \quad \forall c', \quad \forall k \tag{A.6}$$

and

$$\sum_{c=1}^{C} \frac{\partial l_c}{\partial L} = 1 \tag{A.7}$$